An Evaluation of the Risk of Water Shortages in the Lower Peninsula, Virginia

March 1, 2001

IWR Special Study

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Executive Summary

IWR Panel Recommendations Regarding the Regional Raw Water Study Group's Demonstration of the Need for Additional Water Supplies

The Institute for Water Resources (IWR) has been asked by the Norfolk District of the U.S. Army Corps of Engineers to review studies of the future water demand and supply in the service area of the Regional Raw Water Study Group, a consortium of water utilities representing Newport News, Hampton, Poquoson, Williamsburg, York County, and James City County, Virginia. In an October 2000 report, an IWR Panel (John J. Boland, Jerome B. Gilbert, and William J. Werick) advised the Norfolk District that the applicant's demand studies did not show an imminent need for additional water supplies. The IWR Panel also recommended that a collaborative risk assessment examining a range of possible future water use and a variety of solutions, including augmented supply, would be preferable to the adversarial point forecasts provided earlier.

This report reviews new studies recently completed by the applicants, partly in response to the IWR Panel's critique of early work. The report reflects the opinions of the Panel. However, working at the direction of the Panel, Benedykt Dziegielewski, Jack Kiefer, Joel Massmann, and Richard N. Palmer conducted various analyses as well as a detailed review of the applicant's new reports. The Panel has examined the assumptions, methods, results, and interpretations contained in the new studies submitted by the applicant. With the assistance of its consultants, the Panel has replicated the demand, supply, and deficit analyses of the applicant, both to verify reported results and to test the sensitivity of those results to key assumptions.

This report presents the Panel's findings. They are summarized below and are presented in greater detail in the body of this report.

The Panel finds that its prior recommendation of a collaborative risk assessment for future water supply needs has been at least partially satisfied by the new studies reviewed here. It can be noted that the scope of collaboration was significantly limited (perhaps inevitable given the history of this permit application) as was the consideration of many of the economic and social variables that could impact the acceptability of various outcomes.

The Panel and HDR are very close in their estimates of future water use and supply. The Panel's estimate of probable 2050 demands is about 5% less than HDR's because we believe they overestimated unaccounted for water and market penetration. Our point estimate of groundwater yield is the same as HDR's, but our probabilistic estimate is a little higher because we allow for the possibility of higher yields. Our estimate of the safe yield of the current surface water supply is 56.7 mgd compared to HDR's 56.5 mgd. HDR concludes that the region will need more water by 2010, based on Newport News' use of 33% dead storage and the Virginia Department of Health's rule that utilities not rely on drought curtailments to assess the adequacy of their supplies. Based on those two assumptions, the Panel estimates the region will need more water by 2015.

The Panel also calculated shortfall probabilities assuming 20% dead storage and the use of drought curtailments. The assumptions on dead storage and drought curtailment used by HDR are at least arguable. The Department of Health has agreed to a much lower dead storage and Newport News has a drought contingency plan and had used drought curtailments. Based on the use of 20% dead storage and drought curtailments, both of which have been used in practice, the Panel believes the region will need more water supply by about 2025.

The Panel also believes that James City County has shown its intent to develop a desalinated groundwater plant. HDR concluded the plant would probably be built, and the Panel believes it should be considered in the analysis as an alternative to the King William Reservoir. Newport News argues that its net contribution to the yield of the system would be only 2, not 5-6 mgd. The Panel's analysis of groundwater studies suggests that the expected yield will be between 2 and 6 mgd. Yield from this source would mean that the region will have adequate supply for a few years beyond the dates noted above.

The biggest difference between the Panel and HDR is in how we present the results. HDR shows the probable difference between future water use and the minimum expected supply (safe yield). The Panel has criticized this approach in past reports, since the system will produce more water than the safe yield about 98% of the time. The latest RRWSG reports confirm this.

The Panel reports on the risk that supply will be inadequate. Figure 1 shows the risk that supply will be inadequate in each of the forecast years with no additional water supply under two assumptions; (1) 33% dead storage and no drought curtailments, and (2) 20% dead storage with drought curtailments. Figures 2 and 3 show the risk that supply will be inadequate with additional supplies of 5, 10, 15, 20, 25 mgd under the two operational assumptions. Supply is considered inadequate in any year where water use is not satisfied in any month. The analysis considers the worst drought in the 20th century, as Virginia rules require. The risk percentages shown capture the full range of probable demand and supply, not just point estimates. To reduce the risk to zero, the following amounts of additional water supply would be needed:

Additional supply needed to eliminate risk of shortage

	2000	2010	2020	2030	2040	2050
No DCP, 33%	0	0	11	17	25	32
DCP, 20%	0	0	0	8	16	23

These amounts correspond to the upper limit of Figure ES-1 in the HDR Report. These values are derived from a risk assessment that assigned a range to each water use category to capture the uncertainty in forecasts. Zero risk means that this amount of water would satisfy the highest levels of water use in those ranges under any of the hydrologic conditions experienced in the twentieth century.

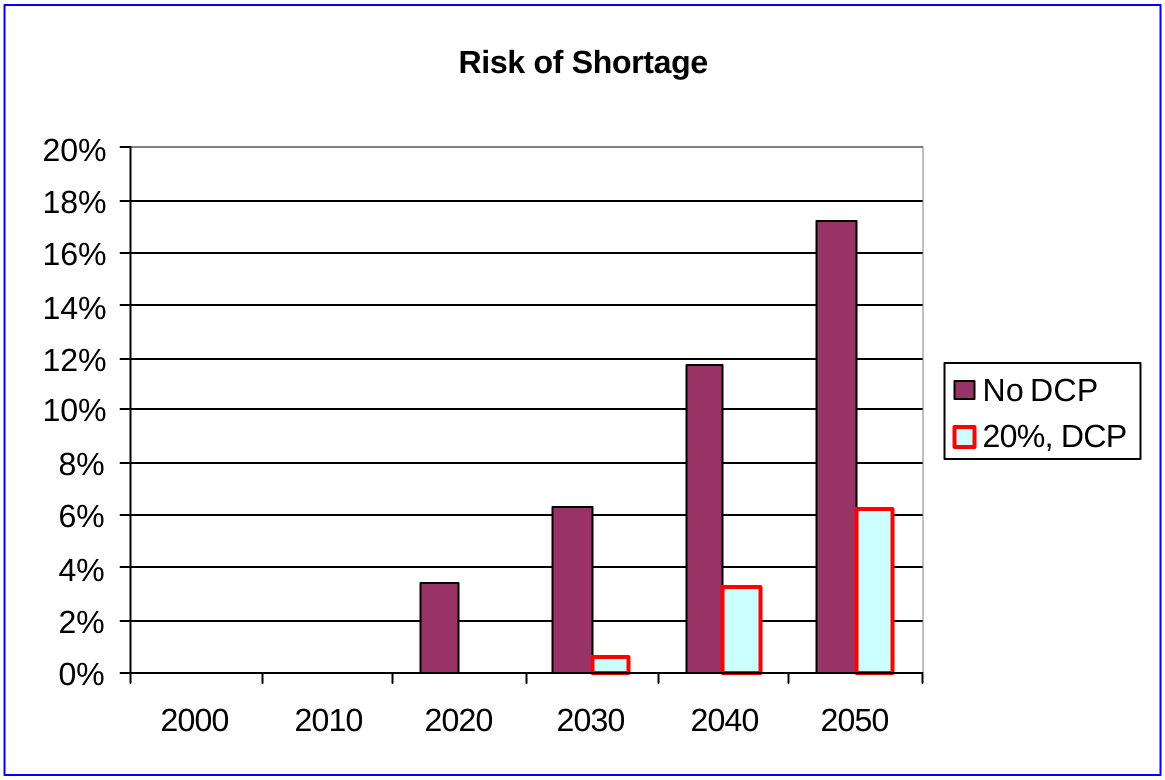

Figure 1. Probability That The Existing Water Supply Will Be Inadequate

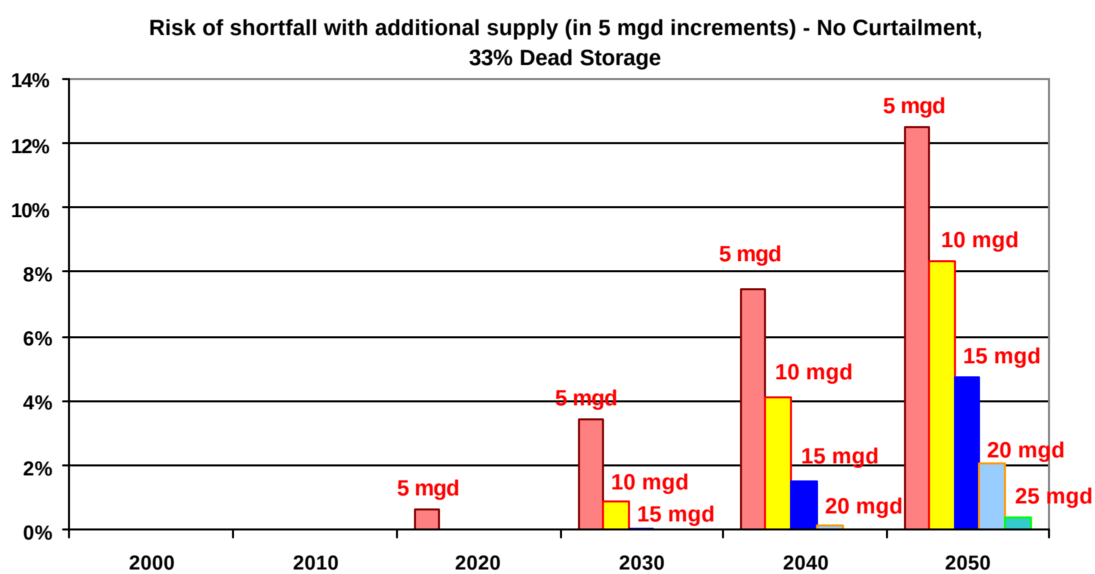

Figure 2. Probability That Water Supply Will Be Inadequate If Supplemented By New Supply, Assuming No Curtailment During Drought And 33% Dead Storage

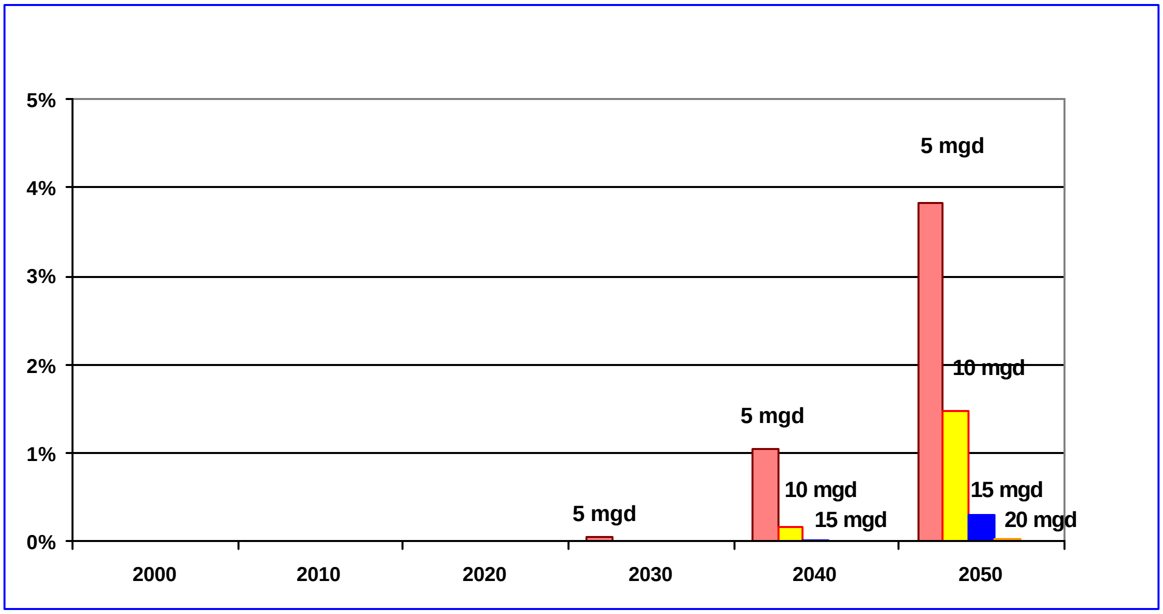

Figure 3. Probability That Water Supply Will Be Inadequate If Supplemented By New Supply, Assuming Curtailment During Drought And 20% Dead Storage

Notwithstanding the criticisms and exceptions described above, the Panel finds that the RRWSG has demonstrated a need for additional water supply sometime between 2015 and 2030 depending on the criteria used by decision makers.

There will be a sequence of tasks that must be accomplished before any new source of water is in place. If there are tasks that must be taken now to assure timely delivery of water supply when it is needed, then decisions on those actions should be taken immediately based on this assessment of need and other assessments of costs and impacts.

Introduction

In November 1998 the Norfolk District of the U.S. Army Corps of Engineers asked the Institute for Water Resources (IWR) to review studies of the future water use in the service area of the Regional Raw Water Study Group, a consortium of water utilities representing Newport News, Hampton, Poquoson, Williamsburg, York County, and James City County, Virginia. The District's concern stems from its responsibility under the Clean Water Act to decide whether the issuance of a permit to build the proposed King William Reservoir is not contrary to the public interest. IWR is the Corps center of expertise for water use forecasting and water conservation. IWR formed a panel composed of William Werick, Dr. John Boland, and Jerome Gilbert. In June 1999, IWR's expert panel provided a draft report on its analysis. The panel concluded that the City's single-point forecast of demand and deficit did not provide a persuasive argument for development of the reservoir. To illustrate this, the Panel performed an alternative calculation that used the same forecasting approach and most of the same data, but which replaced certain questionable assumptions with more plausible numbers. The panel's alternative calculation does not support Newport News' statement of need for the Reservoir. Newport News reviewed and criticized the draft report, citing fifty-one "mistakes and errors". The panel appeared before the city, its contractors, and representatives of the Commonwealth of Virginia on December 17, 1999 so that individual panel members could be questioned independently and polled on their contributions to and support for the report findings. Each member of the panel affirmed his unqualified support for the IWR report. Each member of the panel also stressed, however, that their report had argued against the use of any fixed estimates of demand, including IWR's. The panel agreed that only a collaborative risk assessment could suitably address the uncertainty in the forecasts and the risks of building or not building the reservoir. A collaborative risk assessment would consider a broad range of possible future water use, and the benefits and costs - environmental, financial, social and economic - of alternative methods of meeting the range of future needs. IWR subsequently furnished the Norfolk District more specific information on what such a study would entail.

In December 2000, the district asked IWR to review a new set of reports from the RRWSG meant to address concerns raised by IWR and the district. These reports included:

- A letter to the District Commander from Randy Hildebrandt, Assistant City Manager, dated November 30, 2000 with attached letter of support from Newport News Shipbuilding
- Water Needs Assessment 2000-2050, November 2000 by HDR Engineering, Inc.
- Reevaluation of Critical Drought Condition and Safe Yield of Existing System, June 2000, by Camp Dresser & McKee
- Groundwater Availability in the Chickahominy-Piney Point Aquifer for the Lower Peninsula, October 2000, Malcolm Pirnie Inc.
- Letter report on October 2000 IWR Study dated November 29, 2000 with 4

attachments from Dept. of Health

- Water Supply Alternatives Cost Projection Notebook, November 2000, by Malcolm Pirnie, Inc.

Mr. Hildebrandt's letter summarized the results from these studies: "Together, these reports demonstrate that the RRWSG has a clear and undeniable, need for additional water supplies. The Peninsula's unmet need ranges from approximately 13 mgd to 35 mgd by the end of the fifty-year planning horizon depending on how the underlying variables are combined. Using a risk-based Monte Carlo computer simulation produces a narrower range of 22 mgd to 27 mgd as our probable future (250) deficit." (The Monte Carlo method is explained on page 22.

The Panel enlisted the help of Jack Kiefer and Benedykt Dziegielewski in review of the new water use forecasts and conservation studies, Joel Massmann for the review of probable groundwater yields, and Richard N. Palmer in the review of the safe yield of the reservoir system.

The Panel sought to determine if the conclusions in the new reports were defensible and if the projected needs were supported. Our intent in developing a parallel analysis of our own was to quantify any doubts we had (if any) about the projections. Since we were able to review supply information for the first time, we believed that the results from our parallel studies would be more reliable than our past estimates, which were based on detailed water use analysis and brief reviews of summary data on water supply.

We review the HDR point estimates of demand by category, then the point estimates of future water supply. We then consider how those estimates were used in the risk assessment, including the drought severity analysis and the use of drought contingency plans to improve system reliability.

DEMAND

Purpose

This section describes the methodology, data, and assumptions that were used in preparing the forecasts of water use as presented in the HDR Report. The main features of the forecasting method are summarized below. The sub-sections that follow review the population and land-use projections, point estimates of water use in the major sectors and related assumptions about unit-usage rates. Additional comments are made on the analysis of potential water conservation measures, and review of assumptions and results of the uncertainty analysis in projecting future water use. The section concludes with a summary of principal findings of the review.

Projection methodology

The forecasting method used in the HDR report is a single-coefficient sectorally disaggregated method. Accordingly, estimates of future water use are a sum of products of projected values of demand drivers (persons and acres) and unit rates of water usage (per capita and per acre average daily rates). The water demand forecasting methodology in the HDR report exceeds typical industry practice with respect to treatment of uncertainty around point estimates. However, the general land-use based forecasting approach cannot explicitly address several other factors that are likely to influence rates of water use in the future.

The current (1999) water use in the study area is 55.7 million gallons per day (mgd) and the population served is 421,281 persons. There are certain differences in the forecasting methods used in the HDR Report relative to the methods used in the Final EIS. The following reflect the primary differences:

- Future population and employment forecasts are derived from a regional growth model (an input-output table) for Lower Virginia Peninsula developed by Regional Economic Models, Inc.
- An economic base study summarized in a 19-page Appendix B of the HDR Report, was conducted to review the changes in population, employment, economic activity, natural resources during the 1970-1999 period in the 521 square mile RRWSG study area.
- A land-use approach is used to forecast residential, commercial, and industrial demands. Developed acreage is adopted as the primary driver of future water use instead of population and employment, which represent the primary demand drivers used in FEIS and the IWR Panel Report. However, since population projections influence the rate of development of future acreage, population plays a significant role in the forecasts of residential water demand.

- Analysis of baseline water usage and 11 potential water conservation measures was conducted by Maddaus Water Management, which suggests only a minimal potential for future water conservation in the RRWSG service area.
- Probability distributions encompassing point estimates of future demands are developed using Monte Carlo simulations based on assumed probability density functions of selected forecast input values. An evaluation of the risk-based forecasting results is presented later in this section.

The HDR report provides projections of water use for the 2000-2050 time period in ten-year (decadal) increments. The HDR forecast is extended 10 years further than in the Final EIS. Thus, analysis of data for 2040 can serve as a basis of comparison with the previous report of the IWR Expert Panel.

Most Likely Population Growth Projections

Population projections form the basis of the forecast of future water use in RRWSG service area. A commonly used assumption is that water use will be increasing at the same rate as the rate of population growth. While this assumption is imprecise, the growth in resident population is linked with projected water use through the growth in housing and employment or land use. This sub-section reviews the historical estimates and future projections of population in the study area. The projections used in the HDR report are compared to the projections used in the FEIS and the IWR Panel report. Additional comparisons are made between the historical and projected population as well as “external” state and federal projections. Generally, it appears that the most likely population projections produced by the REMI model are supportable from review of these secondary sources.

Projections of population are a result of the REMI regional growth model, which may be described as dynamic input-output model that translates estimates of regional gross domestic product into estimates of labor demand. Population in- and out-migration is driven by conditions in the labor market (i.e., jobs lead population). The data upon which the REMI model is calibrated come from respected sources, such as the Bureau of Economic Analysis, Bureau of Labor Statistics, and County Business Patterns.

The regional growth model produces a most likely estimate of the 2040 population of 606,751 persons, which represents an increase of 149,056 persons from the estimated 2000 population of the study area of 457,695. The most likely forecast of population represents approximately a 0.71 percent annually compounding growth rate. The 2040 estimate for population exceeds the IWR Panel estimate of 565,670 by 41,081 persons (see Table 1).

Table 1. Comparison of Demand Drivers

Description of Parameter or Estimate	Current 1999-2000 Conditions	2040 Value Used in Final EIS	2040 Value used in IWR Panel Center of Opinion	2040 Value Used in HDR Report
DEMAND DRIVERS				
Population served (persons)	421,281	599,848	565,670	606,751
Heavy Industry employment (employees)	35,792	51,565	28,867-48,665	28,000[a]
CI and Light Ind. employment (employees)	224,733	238,170	224,561-244,359	320,000 [a]
Total CIL and Industrial employment served	260,525	289,735	253,428-293,024	348,000 [a]
Total Single-Family Residential acreage (acres)	44,725			78,463
Low-density Single-Family acreage (acres)	16,171			40,143
Medium-density Single-Family acreage (acres)	23,460			31,945
High-density Single Family Acreage (acres)	5,093			6,375
Total Multifamily Residential acreage (acres)	5,423			7,823
Low-density Multifamily acreage (acres)	2,563			3,884
Medium-density Multifamily acreage (acres)	2,767			3,838
High-density Multifamily Acreage (acres)	93			102
Commercial retail acreage (acres)	5,109			8,728
Commercial business acreage (acres)	3,186			4,792
Light industry acreage (acres)	4,029			6,147
Heavy industry acreage (acres)	5,593			6,580
Parks and public acreage (acres)	14,054			15,083

[a] The values for the year 2040 are read from Figures 3-10 and 3-15 of the HDR report.

Verification of population projections

For verification purposes, Table 2 compares the historical changes in population of the RRWSG study area during the 1970-1999 period with the projected growth during the 50-year period of 2000-2050.[1] The estimates show that the annual growth in the study area population fluctuated between a negative rate of –0.85 percent in 1979-1980 and a 2.52 percent in 1980-1981 (see Figure 3). These annual growth rates are plotted in Figure 3 below.[2] The average annual growth during the 29-year historical period from 1970 to 1990 was 1.15 percent. The average annual population increase was 4,334 persons. The annual growth rates over the three decadal periods were: 0.76 percent during the 1970s, 1.68 percent during the 1980s, and 0.99 percent during the 1990s.

The last six rows of Table 2 show the "most likely" population projections for the RRWSG study area as presented in the HDR Report. The forecast value for the year 2000 shows an increment of 12,920 persons above the 1999 value. The projected population for all benchmark years during 2000 and 2050 are obtained by adding an average annual increment of approximately 3,730 persons. As a result, the decadal percent rates of compounded growth decline from 0.79 percent in 2000-2010 period to 0.60 percent in 2040-2050 period. While the first increment of 12,920 persons (i.e., for the year 2000) is not typical for the historical data series, the annual increment of 3,730 persons during the forecast period is slightly below the average annual increment during the 1970-1999 period.

For comparison, Table 3 provides long-term population projections by the U.S. Census for Virginia. These projections for the State of Virginia show both a declining annual increment and declining annual percentage growth. In contrast to the federal projections, the projections prepared by the Virginia Employment Commission (VEC) show a constant annual increment of population during the three decades after 2000 (see Table 4). Also, these annual increments are significantly higher than those in the federal forecast.

Finally Table 5 compares population projections from the HDR report to those developed by VEC for the communities that make-up the RRWSG. The comparison year is 2010. As shown, differences between the two sources essentially balance out such that the HDR forecast value for 2010 is lower than the corresponding VEC projection. The table also points out a slight discrepancy between the summation of 2010 projections of population in each community and the most likely projection for the RRWSG.

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[1] . The historical data were compiled from the existing on-line data maintained by the U.S. Census at http://www.census.gov/population/estimates/county/ for Virginia.

[2] The extreme values may be the result of a lump adjustment in the data after the 1980 U.S. Census. However, similar negative and positive annual growth rates are found in other years.

Table 2. Historical and projected population in RRWSG area

Year	RRWSG Area Population	Annual Population Increment	Annual Growth (%/year)
1970	319,081	--	--
1971	324,100	5,019	1.57
1972	331,200	7,100	2.19
1973	333,200	2,000	0.60
1974	335,700	2,500	0.75
1975	337,500	1,800	0.54
1976	343,000	5,500	1.63
1977	347,000	4,000	1.17
1978	349,000	2,000	0.58
1979	347,300	(1,700)	-0.49
1980	344,342	(2,958)	-0.85
1981	353,052	8,710	2.53
1982	358,072	5,020	1.42
1983	361,881	3,809	1.06
1984	365,531	3,650	1.01
1985	369,609	4,078	1.12
1986	374,803	5,194	1.41
1987	382,116	7,313	1.95
1988	390,681	8,565	2.24
1989	398,954	8,273	2.12
1990	406,806	7,852	1.97
1991	412,514	5,708	1.40
1992	421,886	9,372	2.27
1993	426,778	4,892	1.16
1994	432,868	6,090	1.43
1995	435,823	2,955	0.68
1996	434,758	(1,065)	-0.24
1997	437,106	2,348	0.54
1998	440,543	3,437	0.79
1999	444,775	4,232	0.96
Average	--	*4,334*	*1.15*
2000	457,695	12,920	2.90
2010	494,938	3,724	0.79
2020	532,195	3,726	0.73
2030	569,466	3,727	0.68
2040	606,751	3,729	0.64
2050	644,049	3,730	0.60

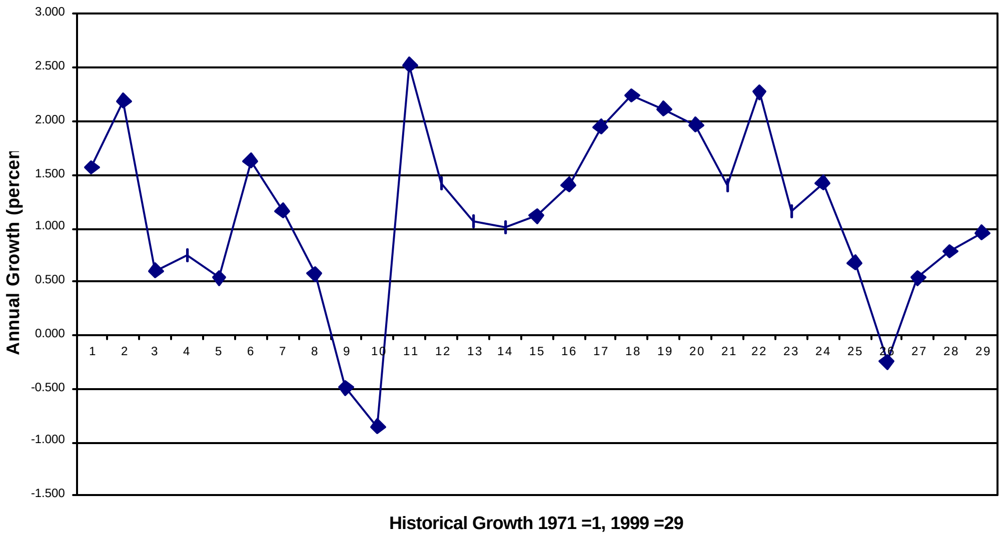

Figure 3. Annual Rates of Population Growth in RRWSG area: 1970-1999

Table 3. Federal population projections for Virginia: 1995-2025			
Year	Population	Annual Increment	Annual Growth (%)
1995	6,618,000	--	--
2000	6,997,000	75,800	1.12
2005	7,324,000	65,400	0.92
2010	7,627,000	60,600	0.81
2015	7,921,000	58,800	0.76
2020	8,204,000	56,600	0.70
2025	8,466,000	52,400	0.63

Table 4: State population projections for Virginia: 1990-2030			
Year	Population	Annual Increment	Annual Growth (%)
1990	6,230,000	--	--
2000	7,023,000	79,300	1.21
2010	7,828,000	80,500	1.09
2020	8,632,000	80,400	0.98
2030	9,437,000	80,500	0.90

Table 5. VEC vs HDR population for 2010			
Jurisdiction	2010 Population By VEC	2010 Population in HDR Report	Difference
Hampton City	142,999	142,506	-493
Newport News City	189,998	190,860	+862
Poquoson City	12,608	13,087	+479
Williamsburg	13,402	13,933	+531
James City County	60,001	76,623	+16,622
York County	78,002	66,646	-11,356
Total RRWSG	**497,010**	**503,655**	**+6,645**
HDR Forecast Value	**--**	**494,938**	**-2,072**

Percent of Population Served

A new assumption of the HDR report is that 100 percent of the area population will be served in the future by the public water supply systems in the study area after 2030. This assumption is implemented via the land use projections. According to the HDR report, all developable single-family acreage is assumed to be on public water systems supplied by the RRWSGG. According to data on Table E-3 of the HDR Report (page E-8), the total current population served is 421,281 persons, which represents 92 percent of the current total population of 457,695 in the RRWSG area. The additional 8 percent of the population in 2040 implies approximately 48,540 persons.

Land Use Projections

The land-use projections are used as a primary driver of water demand in nonresidential sectors. Projections of land under residential development are used in the uncertainty analysis for residential water demands. In both instances, the increases in total acreage of land in residential, commercial and industrial uses are translated into estimates of future water use. This subsection examines the land-use projections and compares them to the projections of the resident population and employment.

The land use analysis provided in the HDR report is internally consistent in that estimates of future population and economic activity are supportable within the developable land base. As shown in Table 1, projections of total employment in the region for 2040 exceed the center of opinion estimates by at least 50,000. However, a major change in forecasting methodology relative to the FEIS Report is the substitution of the land-use based forecast in the HDR Report for the per employee forecasting approach used earlier.[3] The land-use-based forecast assumes that the future nonresidential water use will be proportional to the acreage of land under commercial and industrial development. Another implicit assumption is that the quantity of land for development provides an upper bound for growth. As suggested in the listing of demand drivers of Table 1, there are no comparable figures to evaluate the assumptions for developed acreage. However, Table 6 compares the rates of growth in land use relative to the projected growth in population and employment.

Table 6. Relative growth in demand drivers in the 2000 assessment

Demand Driver	Current (1999) Value	2040 Projection	Percent Change
Population served	421,281	606,751	+44.0
Commercial employment	224,733	320,000	+42.4
Commercial land use (acres)	8,295	13,520	+63.0
Industrial employment	35,792	28,000	-21.8
Industrial land use (acres)	9,623	12,727	+32.3

The estimates in Table 6 indicate that the land-use based forecast for the commercial sector assumes that the percentage increase in developed land for this sector will be greater than the percent increase in projected population and projected employment (i.e., 63.0 percent versus 44 percent increase in population and 42.4 increase in commercial employment as projected by REMI on Figure 3-15 of HDR report). . If the rate of growth of acreage in the commercial sector is assumed to equal the rate of growth of population, then commercial demand in 2040 would be 2.05 mgd lower than referenced in the HDR report.

The projected increase in industrial land use of 32.3 percent is lower than the projected percent increase in population but much higher than the projected negative growth in industrial employment. Although it is important to recognize that the decline in the number of employees in manufacturing may not translate into reductions in water use due to the expected increases in productivity of labor, the land-use based forecast assumes that the increases in productivity will produce growth in total industrial demands, despite the projection of declining employment.

Percent of Acreage Served

As discussed above, the HDR report assumes that 100 percent of developable single-family acreage is served by the public water system after 2030. Table 7 shows the embedded assumptions for acreage served in the single-family sector over the forecast horizon. Again, these data reflect a difference in assumptions relative to the FEIS, and will produce higher estimates of residential water demand, everything else remaining the same.

[3] It should be noted that residential water use projections are also developed using a land use based approach. Generally, land use and acreage is used to disaggregate residential use into low, medium, and high density development. However, reference to acreage is not necessary to project the combined residential use, which is driven only by population and assumed per capita usage rates.

Table 7. Assumptions for Percent of Single-Family Acreage Served						
	2000	2010	2020	2030	2040	2050
Single-Family Acreage Served	40,252	47,870	55,892	64,316	71,716	78,463
Developable Single-Family Acreage	44,725	51,473	58,220	64,968	71,716	78,463
Percent of Developable Single-Family Acreage	90	93	96	99	100	100

Point Estimates of Water Use

As mentioned at the onset of this chapter, estimates of water use in the HDR report are a sum of products of projected values of demand drivers (persons and acres) and unit rates of water usage (per capita and per acre average daily rates). This subsection examines the 2040 point estimates of water use and compares the sectoral estimates between the HDR report and the FEIS and IWR reports.

Table 8 provides a summary of point estimates of demand and associated sectoral usage rates. The projected year 2040 use is 82.14 mgd (Tables ES-1 and 4-10 of HDR report) and can be obtained through the following calculation of sectoral demands, where the acronyms gpcpd and gpacd refer to gallons per capita per day and gallons per acre per day, respectively:

Residential:	606,751 persons ∗ 60.44 gpcpd	=	36.67 mgd
Commercial retail:	8,728 acres ∗ 660 gpacd	=	5.76 mgd
Commercial business:	4,792 acres ∗ 2,463 gpacd	=	11.80 mgd
Industrial (light + heavy):	12,727 acres ∗ 1,000 gpacd	=	12.73 mgd
Military use:		=	3.97 mgd
Military reserve:		=	3.00 mgd
Unaccounted water:	73.92 mgd * 0.1111	=	8.21 mgd
Total 2040 M&I demand:			82.14 mgd

Table 8. Comparison of point estimates of water demands

Description of Parameter or Estimate	Current 1999-2000 Conditions	2040 Value Used in Final EIS	2040 Value used in IWR Panel Center of Opinion	2040 Value Reported in HDR Report
PROJECTED USAGE RATES				
Total Residential per capita use (gpcpd)	65.3	66.9	59.7	60.6
Total Residential Indoor per capita use (gpcpd)	59.0	60.2	53.0	53.2
Total Residential Outdoor per capita use (gpcpd)	6.3	6.7	6.7	7.3
Single-Family per capita use (gpcpd)	70.5			65.1
Single-Family Indoor per capita use (gpcpd)	62.0			55.4
Single-Family Outdoor per capita use (gpcpd)	8.5			9.8
Multifamily per capita use (gpcpd)	56.9			48.9
Multifamily Indoor per capita use (gpcpd)	54.1			2.9
Multifamily Outdoor per capita use (gpcpd)	2.8			51.9
Retail business usage (gal./acre/day)	660			660
Other commercial usage (gal./acre/day)	2,463			2,463
Industrial usage (gal./acre/day)	1,000			1,000
PROJECTED DEMANDS (mgd)				
Residential Water Use	27.9	43.73	33.2	36.7
Single-Family Residential Water Use	18.6			25.6
Multifamily Water Use	9.3			11.1
CI and Light Industry Water Use	11.3	16.77	15.81-17.20	17.56
Heavy Industry Water Use	9.6	22.38	14.62-8.66	12.72
Combined CIL and Heavy Industry	20.9	39.15	30.40	30.28
Unaccounted Water Use	3.3	9.26	7.52	8.21
Military Water Use	4.0	5.52	4.05	6.97
Total demand (w/o future conservation)	55.7	98.2		
Total demand (w/ future conservation)	55.7	--	75.20	82.14

A slight discrepancy exists between the 2040 combined per capita residential rate reported in the HDR report as 60.6 gpcpd and the rate of 60.44 gpcpd that was required to reconcile the projection of total demand.

The comparison of the values and forecast parameters between the June 1999 IWR Panel Report and the HDR Report shows the following differences:

- Total water demand in 2040 in the HDR Report is 6.94 mgd (9.2 percent) higher than the IWR Panel value (82.14 mgd vs 75.2 mgd)
- The 2040 residential demand of 36.7 mgd in the HDR Report is 3.47 mgd (10.5 percent) higher than the IWR Panel value of 33.2 mgd
- The nonresidential demand (CIL and Industrial) is nearly identical in both reports (i.e., 30.28 mgd in HDR Report vs 30.40 mgd in IWR Panel Report, a –0.12 mgd difference)
- Military demand has been increased by 2.92 mgd to 6.97 mgd by adding a "reserve" of 3.00 mgd and lowering the IWR Panel value by 0.08 mgd (from 4.05 mgd to 3.97 mgd)
- The unaccounted use has been increased by 0.69 mgd as a result of multiplying the sum of sectoral and military demands of 73.92 mgd by 0.1111 (or 10 percent of production)

Therefore, the difference in total year 2040 demand of +6.94 mgd between the two reports is accounted by the above changes as follows:

+6.94 mgd = +3.47 – 0.12 + 2.92 + 0.69 (with a 0.02 mgd rounding error)

In summary, the overall point estimate of 2040 demand in the HDR Report is approximately 7 mgd higher than the "center of opinion" estimate of 75.2 mgd suggested by the IWR Panel. From the data reported in Table 1, and subsequent calculations, the main differences in the future point estimates of water use in the IWR Panel Report and the HDR Report stems from the change in the projected population served and addition of the 3.0 mgd to total future demand as a "military reserve." For example, at a combined residential per capita usage rate reported at 60.6 gpcpd, the difference in population over the center of opinion estimates translates to an increment of 2.49 mgd in total water demand.

Table 9 summarizes the increments in total demand above the actual 1999 use, as projected in the HDR Report. All data have been rounded to one decimal digit. These increments show that the greatest growth in demand is assumed for the commercial, military and unaccounted sectors.

Table 9: Percent change in sectoral demand from 1999 to 2040							
Sector	1999 Use (mgd)	Percent of Total 1999 Use	2040 Use (mgd)	Percent of Total 2040 Use	Change (mgd)	Percent Change (1999-2040)	Percent of Total Change
Residential	27.5	49.4	36.7	44.6	+9.2	+33.5	34.7
Commercial	11.3	20.3	17.6	21.4	+6.3	+55.8	23.8
Industrial	9.6	17.2	12.7	15.5	+3.1	+32.3	11.7
Military	4.0	7.2	7.0	8.5	+3.0	+75.0	11.3
Unaccounted	3.3	5.9	8.2	10.0	+4.9	+148.5	18.5
Total	55.7	100.0	82.2	100.0	+26.5	+47.6	100.0

By 2040, the projected increment of 26.5 mgd in new demands is comprised of 34.7 percent of new residential demands, 23.8 percent of new commercial demands, 11.7 percent of new industrial demand, 11.3 percent of new military demand and 18.5 percent of new unaccounted use. Thus commercial and unaccounted uses are respectively the second and third largest contributors to the projected new demand growth between 1999 and 2040

Assumed Usage Rates per Unit

In order to verify the future point estimates of water use it is necessary to examine not only the projections of population, employment, and land use, but also the assumed unit rates of water use. The previous sections reviewed the difference in growth rates of the main drivers. These differences have a direct effect on the future estimates, which are influenced further by the changes in the rates of water use over time. This subsection compares the usage rates used in the HDR report with the implied rates that are expressed in per person and per employee terms. The evaluation shows only modest changes in per capita and per acre usage rates used in calculating future residential and nonresidential demands. However, the HDR report implies large percentage increases in military and unaccounted usage per capita.

The assumed rates of water usage per accounting unit (i.e., resident or developed acre) are compared in Table 10. The historical rates of usage per person or per acre are not provided in the HDR Report (only the current estimates are shown). The estimates in Table 10 were obtained from the HDR Report either directly or by making simple calculations using the following information:

1. The current gross per capita (gpcpd) rate was obtained by dividing the 1999 demand of 55.7 mgd (Table E-1 of HDR report) by population served of 421,281 persons shown in Table E-3 of the HDR report. The 2040 rate is obtained by dividing the point estimate of 82.14 mgd by projected population served of 606,751 persons.
2. The combined residential per capita rates were obtained from Table 4-2 of the HDR report (p. 4-7). The verification by dividing the reported residential demand by population served yields 65.3 gpcpd for 1999 and 60.44 gpcpd for 2040. Note the

discrepancy with the slightly higher figure of 60.6 gpcpd reported on Table 4-2 of the HDR report.

3. The single-family and multifamily sector rates were obtained from Tables 4-2, E-7, and E-8 of the HDR report.
4. The commercial and institutional usage rate per capita for 1999 was obtained by dividing the reported demand of 11.3 mgd (Table E-1 of HDR report) by the population served of 421,281 persons. The 1999 per employee rate (gallons per employee per day, gped) was given in Table E-3 of the HDR report. The per acre rate is a weighted average of the 695 gpacd for retail business and 2,592 gpacd for other commercial shown for the year 2000 in Table 4-4 of the HDR report (p.4-15).[4]
5. The 2040 rate of 54.9 gallons per day per commercial employee was calculated by dividing the projected commercial use of 17.56 mgd by the projected commercial employment of 320,000 employees, which was read from Figure 3-15 of the HDR report.
6. The industrial per employee rate for 2040 was obtained by dividing the projected industrial use of 12.72 mgd by industrial employment of 28,000, which was from Figure 3-10 of the HDR report.
7. The nonresidential (commercial and industrial rates per acre were obtained by dividing the demands in 2040 by the projected developed acreage.

Table 10. Current and future rates of water use in RRWSG area In 2000 assessment

Description	**Current Rate 1999-2000**	**Future 2040 Rate**	**Percent change**
Gross per capita use (gpcd)[1]	132.2	135.4	+2.4
Combined residential per capita rate (gpcd)	65.3	60.6	-7.2
Single-family residential rate	70.5	65.1	-7.7
Multifamily rate	56.9	51.9	-8.8
Commercial and institutional usage rates			
Per capita rate (gpcd)	26.8	28.9	+7.9
Per employee rate (gped)[a]	51.0	54.9	+7.6
Rate per developed acre (gpacd)	1,423.6	1298.8	-8.8
Industrial usage rates			
Per capita rate (gpcd)	22.8	21.0	-8.0
Per employee rate (gped)	270.0	454.3	+68.3
Rate per developed acre (gpacd)	997.6	999.5	+0.2
Military use per capita (gpcd)	9.5	11.5	+20.9
Unaccounted use (gpcd)	7.8	13.5	+73.5

[a] The future rate represents the 2050 rate instead of 2040 rate.

[4] A slightly smaller rate of 1,362.3 gpacd is obtained by dividing the 1999 commercial water use of 11.3 mgd (Table E-1 of HDR report) by the commercial acreage of 8,295 acres. At the lower rate per acre, the 1999-2040 decrease in commercial usage rate would be –4.7 percent instead of –8.8 percent shown in Table 9.

The gross per capita rate in Table 10 indicates that the total future use is projected in the HDR Report to grow slightly faster than population served. While the per capita rates were not used to generate the most likely forecasts for all sectors, they reveal the projected shifts in sectoral demands that are imbedded in the forecast regardless of the method that is actually used. The sectoral components of the gross per capita rate indicate that the 3.2 gpcd increase between 1999 and 2040 is a net effect of the decreasing per capita rates in residential and industrial sectors and increasing per capita rates in commercial, military and unaccounted use.

Because the comparison of usage rates in Table 10 shows only modest changes in per capita and per acre usage rates used in calculating future demands (except for the large percentage increases in military and unaccounted usage per capita), the growth in population and commercial and industrial acreage are the main reasons for projected growth in residential and commercial demands.

Residential Unit Rates of Use

The HDR report provides estimates of per capita use disaggregated by residential sector and for indoor and outdoor purposes. Single- and multifamily sectors are each comprised of low, medium, and high density development categories. Appropriately, because of assumed higher outdoor use, low density housing is assumed to have higher per capita use. Further, outdoor use is expected to rise in the low density categories as new development occurs in more rural areas. Overall, however, total per capita rates of use in both the single- and multifamily sectors are assumed to decline by 2040. The combined (single-family plus multifamily) residential per capita rate of use for 2040 is less than 1 gallon per day higher than the IWR's Center of Opinion estimates (60.6 gpcd vs. 59.7 gpcd).

Nonresidential Unit Rates of Use

The forecast for nonresidential sectors uses four different rates of water use per acre. The starting rates for the year 2000 include 695 gallons per acre per day (gpacd) for retail business; 2,952 gpacd for other commercial; and 1,020 gpacd for industrial use. In 2040, these rates are slightly decreased and are: 660 gpacd for retail; 2,437 gpacd for other commercial; and 1,000 gpacd for industrial. The effective nonresidential sector rates, which are obtained by dividing the total usage in each sector by total acreage, are shown in Table 9. They indicate an 8.8 percent decline in the combined commercial rate between 2000 and 2040 and approximately unchanged rate for the industrial sector.

When examined with respect to the projected population and employment, the effective rates for the commercial sector show a slight increase in the commercial use per capita (i.e., +2.1 gpacd or 7.9 percent) between 2000 and 2040. A similar increase is implied for the commercial per employee usage rate between 2000 and 2040. This comparison of the usage rates per acre with the rates per capita and per employee indicates that the assumed lower rate per acre in 2040 is slightly more than "compensated" by the growth rate in total commercial acreage relative to the growth rates of population and employment.

The industrial rate per capita shows a slight decrease between 2000 and 2040. A major increase in the per employee rate (i.e., +68 percent above the current rate) is in effect for 2040. This implies that rate of growth in industrial acreage substantially exceeds the growth in employment (actually the industrial employment is expected to decrease by 2040). However, this difference does not imply an overestimate of industrial water use, it only indicates that the future gains in productivity of labor, which result in increased water use per employee are already built into the projected values of industrial acreage.

Military Use

It is not clear whether future water needs can be predicted based on heavy military-related industry practices of the past, particularly those of the World War II period. However, the evaluation of the military buildup period does illustrate the special circumstances in the Newport News area. The military reserve of 3.0 mgd cannot be viewed as a part of a "demonstrated need," although it may be a part of prudent planning. A military use contingency is not unreasonable given the history of military investment in the area and the unquantified estimates of additional needs expressed in the August 22, 2000 letter from Newport News Shipbuilding to Mayor Joe S. Frank.

Unaccounted for Water Use

Despite various references to metering non-revenue water (flushing water, for example), the unaccounted water (UAW) percentages cited in the HDR demand forecast are conventionally defined: they represent the difference between treated water production and metered water sales. Because of the layout of the Lower Peninsula water supply systems and the chosen definition of UAW, losses from raw water transmission mains are not included in UAW. Instead, these losses were estimated based on two water balance trials that make it impossible to separate raw water distribution losses from reservoir seepage. HDR chose to handle these losses by measuring supply in terms of treated water production, rather than raw water withdrawals. Given these definitional issues and review of various details of system management the current estimate of 6.3 percent UAW is plausible and well supported.

In its October 2000 Final Report, the IWR Panel accepted the RRWSG assumption that unaccounted for water (UAW) would increase from approximately 6% in 2000 to 10% in 2040. In reaching this conclusion, the Panel noted the low level of reported UAW (as compared to industry norms) and expressed concerns about the accuracy of metering. The Panel accepted RRWSG representations regarding leakage control and metering of non-revenue uses.

These new reports have provided additional information on the question of UAW and water losses in general. It is now possible to assemble a more detailed picture of water losses and of the assumptions used by HDR in estimating capacity requirements.

HDR defines water supply as the volume of treated water available at the effluent of the water treatment plant (or equivalent location for groundwater). Losses prior to that point are treated as deductions from supply, while losses that occur after that point are added to demand.

Briefly and generically, the major components of the water balance for a fully metered system are as follows:

A. Reservoir inflow
B. Controlled downstream releases from reservoirs
C. Reservoir spills
D. Seepage
E. Net evaporation from reservoir surface
F. Net gain in stored water
G. Reservoir withdrawals
H. Groundwater or direct stream withdrawals
I. Raw water transmission losses
J. Net water lost in treatment processes
K. Treated water production
L. Distribution system leakage
M. Distribution system flushing water
N. Other authorized withdrawals from hydrants
O. Unauthorized withdrawals from distribution system
P. Water sold through customer meters (revenue water)

Water balance at the reservoir is defined as:

$$A - B - C - D - E - F = G$$

Raw water flows into the system are:

$$G + H$$

The water balance for the rest of the system is:

$$G + H = I + J + K$$

Where:

$$K = L + M + N + O + P$$

Of the sixteen components identified here, most must be estimated as they are not measured or otherwise observed. When flows are measured, the metering devices may vary widely in accuracy. In the case of Newport News Waterworks, it has been represented that production meters (K) and customer meters (P) are well maintained and of acceptable accuracy. Newport News also meters at least some part of flows M and N. No information is available on metering or flow estimates at other points.

The HDR report defines supply in terms of "treated water safe yield." This is described as "raw water" adjusted for losses. "Raw water" yields are determined by modeling, as described in the CDM report. For a system like Newport News, with impoundments, direct intakes, and groundwater, the "raw water" measure can be described as:

Raw water = A - B - C - F + H

The HDR report speaks of evaporation losses (E), reservoir seepage losses (D), and treatment losses (J).

Supply losses = D + E + J

Then,

Treated water = raw water - supply losses = A - B - C - F + H - D - E - J

Note that raw water transmission losses (I) are not separately identified; they are bundled with seepage losses. Since treated water is metered, all supply losses must have been accounted for in a safe yield metric defined on treated water. For the Newport News system, reservoir seepage is estimated at 4 mgd. There is no information on reservoir stage at the time of the measurement, except that the water surface was below the spillway crest. True seepage must be positively correlated with reservoir contents, but that relationship would not apply to any part of the 4 mgd that is actually transmission loss. The length and size of the transmission mains in use suggest that this leakage may be on the order of 1 or 2 MGD.

The UAW fraction used in the HDR report is defined as follows:

UAW = (K - P)/K = (L + M + N + O)/K

Appendix E of the HDR report states that unaccounted for water reached 2.8 percent in 1999 due, in part, to the metering of flushing water and other withdrawals from hydrants (M and N). This indicates a different definition of UAW, namely:

UAW' = (K - M - N - P)/K = (L + O)/K

Assuming the O is negligible, the 2.8 percent figure reflects distribution system leakage (L) only (plus the net effect of cumulative meter misregistration) and appears quite plausible. The 6.3 percent number actually used by HDR for the base year of their forecast (2000) apparently includes all nonrevenue water (hydrant flows as well as leakage). Given the 2.8 percent estimate of leakage, and supposing that it can be applied to the entire RRWSG service area, the 6.3 percent figure implies flushing and other hydrant flows amounting to 3.5 percent of production. This amount also appears plausible and well supported.

HDR proposes that UAW will increase over time, reaching 10 percent by 2040. For this to happen, either leakage, or flushing, or both would have to increase dramatically. While flushing requirements may well increase beyond current levels, they are unlikely to double. Similarly, given present management practices leakage is unlikely to increase greatly, even as the system ages. For these reasons, the Panel judged that UAW could grow to 8%.

Evaluation of Water Conservation Analysis

Future rates of water usage per employee and per acre depend on the potential for future water conservation. Future effects of water conservation measures have to be quantified and used to adjust downward the forecast of water use. The effects of conservation are imbedded in the assumed rates of future water use. This subsection reviews the analysis of water conservation potential that was presented in Appendix E of the HDR Report.

The appendix contains a brief summary of the analysis of potential long-term water conservation measures for the RRWSG area. Although a complete verification of the conservation analysis is not possible due to a very limited presentation of relevant historical water use data, the following observation can be made on the basis of information that is presented in the report.

1. On page E-4, the report mentions a "flat" demand in the Newport News Waterworks (NNW) service area during the 1990s despite the growth in the total number of service connections. The declining usage rates per account are presented on page E-10 showing a decrease from 484 gallons per day per connection (gpdpc) in 1982-85 to 456 gpdpc in 1986-90 to the current rate of 410 gpdpc. This represents a 1.04 percent decline per year over the 16-year period. Similarly, average water use per *residential* connection was reported to have decreased from 252 gpdprc in 1982-85 to 234 gpdprc in 1986-90 to a current rate of 231 gpdprc, a 0.55 percent annual decrease. While these changes are attributed to the recent and ongoing water conservation programs, the actual causes have not been investigated but may be related not only to improvements in efficiency of water use but also to some structural changes in demand. Examples of possible structural changes include increasing share of residential accounts in total service connections or a declining size (in terms of average water use) of new commercial and industrial accounts relative to the average size of existing accounts. In terms of efficiency gains, the new residential connections may be significantly more efficient and using less water per household than the existing accounts. These trends, especially the structural changes, may persist in the future thus affecting the future unit rates of water use in individual sectors.

2. On page E-14, it is reported that the maximum total conservation potential of all evaluated measures, on a system wide basis is only 3 mgd. Because, this quantity represents only 5 percent of the current demand and only 3 percent of the 2050 demand, it can be viewed as a relatively minor conservation target. The subset of cost-effective measures reduces this potential to approximately 1.0 mgd.

3. A possibly questionable result is the effectiveness of the CII measure (commercial, industrial and institutional), for which the reported average water savings during a 30-year period were found to be only 0.11 mgd or only 0.4 percent of the combined commercial and industrial demand in 2030 and which was found not to be cost-effective.

4. The set of potential long-term measures does not include any future pricing strategy, especially those changes that would be necessary to finance the contemplated development of the proposed reservoir and related infrastructure. A cursory analysis of the recent pricing reform in the NNW service area (elimination of blocked tariff and adoption of seasonal pricing) suggest that those changes had a significant effect on system wide water use.

5. The benefit-cost analysis reported on Table E-6 includes only benefits associated with the short-term variable cost of water production (avoided cost of energy and chemicals). Because the avoided costs of infrastructure associated with the proposed reservoir were not included, the benefits of all evaluated measures were underestimated.

In summary, the analysis of water conservation is limited in the scope of potential measures, especially measures aimed at nonresidential customers, and omits benefits from the deferred, downsized or eliminated long-term water supply investments. Also, only a qualitative analysis of the effectiveness of the past and current conservation efforts is provided. As a result, the conclusion regarding the limited future conservation potential is questionable. The implicit conservation in the forecast is imbedded in the unit rates of the residential and commercial sectors with reductions of 7.2 and 8.8 percent, respectively, as shown on Table 10. No such direct (before vs. after) conservation effects are assumed for the industrial, military and unaccounted uses.

Review of analysis of uncertainty in water demands

In the HDR Report, a significant effort was devoted to developing probability distributions that encompass the "most likely" point estimates of the sectoral and total demands. The resultant distributions provide information on the probability that the point estimates will be exceeded or the probability that the future water use will fall within a give range of possible values. Also, a concentration of simulated values close to the point (or "most likely") estimates can be taken as an indication that the most likely value is well chosen. However, the shape of the simulated probability density functions is critically dependent on the selection of low, medium and high points for probability density functions of input parameters and the assumed correlation between input variables. The HDR report was reviewed in order to define the parameters of the probability density functions. HDR and Newport News Waterworks were contacted (on January 12, 2001) to clarify some of the narrative on uncertainty within the HDR report.

Monte Carlo simulation was enacted to generate future values of independent variables. The generated distributions invariably show the most likely (i.e., the best point estimate) on the left side of the distribution, although the differences between the "best point" value and the mean value of the distribution are relatively small. The assumptions used in generating the distribution functions are summarized and discussed below.

A 'Monte Carlo' analysis is a widely accepted mathematical approach for describing the uncertainty inherent in a forecast, when the forecasted variable is itself a function of several underlying and uncertain variables.

In this case, best estimates of water use and water loss were made for each forecast year in several categories on the basis of underlying assumptions about the growth of the region, the long term effects of conservation, and the physical characteristics of the water supply and distribution system. But these assumptions (demand drivers) as well as the resulting water use estimates are all forecasts and inherently uncertain. Therefore, upper and lower bounds are identified for most demand drivers, reflecting the estimated range of possible values. A probability distribution is assigned to each uncertain variable, indicating the relative likelihood of any value within the estimated range.

If the water use or loss in all these categories were dependent in exactly the same way on exactly the same underlying values, it would be relatively simple to calculate the probability that the total water needed would be between two values; but this is not the case. For instance, domestic water use could grow rapidly because of population increases above the best point estimates, while at the same time industrial water use might grow less rapidly than the best point estimate because of unexpected increases in the effectiveness of water conservation. On the other hand, there is some connection between these two categories; job growth is an important factor in population growth, and industrial employment is a part of total employment.

Any mathematical estimate of the probabilities of total water use and loss must account for the diversity of demand drivers and interrelationships among water demands for any combination of water needs across all categories. Conceptually, the simplest way to do this is to literally consider thousands or even millions of combinations of categorical water use, calculate the total water use and joint probability for each combination, and then calculate the probability that total water use will be between two values by summing the probabilities of all the combinations whose water use fell within that range. The burden of doing all these calculations is made possible by computers.

This is essentially what Monte Carlo analysis is. This statistical problem arises in all sorts of risk calculations in and outside water use forecasting, and the Monte Carlo method is a widely accepted method of addressing the issue. Software is commercially available to do these calculations.

The Monte Carlo analysis does not eliminate uncertainty from forecasts of the future. The "answers" from a Monte Carlo analysis still depend on human, fallible estimates. The future sometimes exceeds the upper limits of our forecasts, and sometimes it fails to reach what we believed would be an improbably low number. The "answer" from a Monte Carlo analysis depends on the estimates of dependence between categories; the best point, maxima and minima in each category; and the shape of the probability distribution connecting the three points.

HDR's best point estimates are much less than the point estimates made in the Final EIS and are almost identical to the point estimates made by the IWR Panel. The total of HDR's best point estimates are greater than the Panel's, primarily because HDR added a category that the Panel did not consider separately, a contingency of 3 mgd in case there is a military buildup in the region. This is despite the fact the HDR estimates were based on population forecasts even higher than the FEIS forecast, which is in itself suspect (the current regional population is less than forecast by the early 1990's FEIS forecast).

But the HDR Monte Carlo analysis leads to the conclusion that the best point estimates of water needs are probably going to be exceeded. It may seem illogical or suspicious for HDR to predict that their own best guess is probably low, but it may be entirely reasonable. IWR reviewed the assumptions made by HDR in each category and ran its own Monte Carlo analysis to assure there were no mathematical errors. There are detailed discussions of our analysis in the demand section of this report; our overall judgment is that HDR's analysis is reasonable but generous. That means that if the region plans its water supply based on this analysis, it will probably err on the side of having too much water.

The Panel disagrees with the use of the Monte Carlo method for calculating the surface water supply. Our perspective is discussed starting on page 54.

Assumptions for Residential Demand Simulations

The simulation of residential (single-family and multifamily) water use uses the product of several factors to develop a range of water use estimates in any particular forecast year. The following general relationship is used to develop an estimate of water use in any residential sector and housing density category:

Water Use = Acres * Persons/housing unit * housing units/acre * water use/person

In conjunction with the assumed per capita usage rate, persons per household and density (units/acre) translate the population and acreage estimates into predictions of water use.

Table 11 provides a summary of probability density functions used in the uncertainty analysis. As shown, population is assigned low, medium, and high values, which correspond to the outputs of the REMI growth model. Implied annually compounding growth rates are approximately 0.41 percent, 0.71 percent, and 1.26 percent, for the low, medium, and high population scenarios respectively. In the HDR report, these values were originally used as parameters of triangular distributions. However, as shown in Table 11, the triangular distributions were replaced with a set of log-normal distributions. The shapes of the assumed log-normal distributions are defined by the most likely (point) population projection and a standard deviation equal to 10 percent of the most likely value. According to the HDR report, the sampling from these distributions is truncated and limited to those values including and lying between the minimum and maximum population projections.

Although population is not used directly within the simulation of water demands, its distribution of values is used to distribute future developed acres among the housing density categories. As such, the variables representing residential acreage are assigned log-normal distributions. The most likely point estimates of acreage and an assumed standard deviation of 10 percent of the most likely values define the shape of each distribution for acreage.

The housing density (housing units per acre) variables are assigned triangular distributions. The shapes of these distributions are defined by low, most likely, and maximum values that are assumed for housing density. As shown in Table 11, the assigned distributions reflect a relatively narrow range of density values.

The person per household variable is held constant over the forecast period and is not treated as uncertain. All single-family housing density categories are assigned the same value for persons per household (2.58). Similarly, all multifamily density categories are assigned the constant multifamily persons per household value of 2.3.

Table 11. Assigned Probability Distributions for Uncertainty Analysis								
			Parameter Values					
			Current	Estimated				
Simulation Variables	Distributions	Parameters	2000	2010	2020	2030	2040	2050
Residential								
Population (not directly simulated)	LogNormal (truncated)	Minimum		478,629	499,573	520,525	541,485	562,455
		Mean	457,695	494,938	532,195	564,966	606,751	644,049
		Maximum		535,122	612,574	690,052	767,554	845,083
		SD		49,493.8	53,219.5	56,496.6	60,675.1	64,404.9
Single-family								
Persons per Household	Constant	Value	2.58	2.58	2.58	2.58	2.58	2.58
Low Density								
Acreage	LogNormal (truncated)	Minimum		19,166	22,160	25,154	28,148	31,142
		Mean	16171	20,966	25,760	30,554	35,349	40,143
		Maximum		25,167	34,163	43,159	52,154	61,150
		SD		2,096.6	2,576	3,055.4	3,534.9	4,014.3
Housing Density	Triangular	Low		1.14	1.03	0.97	0.93	0.9
		Most Likely	1.37	1.19	1.08	1.01	0.95	0.91
		High		1.22	1.11	1.03	0.96	0.91
Per Capita Indoor Use (gpd)	Triangular	Low		54	52	50.4	50.4	50.4
		Most Likely	62	59	57	55.4	55.4	55.4
		High		64	62	60.4	60.4	60.4
Per Capita Outdoor Use (gpd)	Constant							
		Value	12	13.8	15.2	16.3	17.3	18.1
Medium Density								
Acreage	LogNormal (truncated)	Minimum		24,641	25,822	27,003	28,184	29,365
		Mean	23,460	25,157	26,854	28,551	30,248	31,945
		Maximum		26,790	30,120	33,450	36,779	40,109
		SD		2,515.7	2,685.4	2,855.1	3,024.8	3,194.5
Housing Density	Triangular	Low		2.89	2.89	2.89	2.89	2.89
		Most Likely	2.89	2.91	2.93	2.95	2.97	2.99
		High		2.94	2.97	3	3.03	3.05
Per Capita Indoor Use (gpd)	Triangular	Low		54	52	50.4	50.4	50.4

Table 11. Assigned Probability Distributions for Uncertainty Analysis

Simulation Variables	Distributions	Parameters	Parameter Values: Current 2000	Estimated 2010	2020	2030	2040	2050
		Most Likely	62	59	57	55.4	55.4	55.4
		High		64	62	60.4	60.4	60.4
Per Capita Outdoor Use (gpd)	Constant							
		Value	8	7.9	7.8	7.8	7.7	7.7
High Density								
Acreage	LogNormal (truncated)	Minimum		5,243	5,393	5,543	5,693	5,843
		Mean	5,093	5,350	5,606	5,862	6,119	6,375
		Maximum		5,651	6,208	6,766	7,323	7,881
		SD		535	560.6	586.2	611.9	637.5
Housing Density	Triangular	Low		4.66	4.64	4.61	4.59	4.57
		Most Likely	4.69	4.66	4.64	4.61	4.59	4.57
		High		4.7	4.71	4.71	4.72	4.72
Per Capita Indoor Use (gpd)	Triangular	Low		54	52	50.4	50.4	50.4
		Most Likely	62	59	57	55.4	55.4	55.4
		High		64	62	60.4	60.4	60.4
Per Capita Outdoor Use (gpd)	Constant							
		Value	6.3	6.3	6.3	6.4	6.4	6.5
Multifamily								
Persons per Household	Constant	Value	2.3	2.3	2.3	2.3	2.3	2.3
Low Density								
Acreage	LogNormal (truncated)	Minimum		2,711	2,859	3,006	3,154	3,301
		Mean	2,563	2,828	3,092	3,356	3,620	3,884
		Maximum		3,128	3,693	4,258	4,822	5,387
		SD		282.8	309.2	335.6	362	388.4
Housing Density	Triangular	Low		8.67	8.3	8.03	7.82	7.65
		Most Likely	9.21	8.84	8.54	8.28	8.06	7.87
		High		8.87	8.57	8.29	8.06	7.87
Per Capita Indoor Use (gpd)	Triangular	Low		48	46	44	44	44

Table 11. Assigned Probability Distributions for Uncertainty Analysis								
			Parameter Values					
			Current	Estimated				
Simulation Variables	**Distributions**	**Parameters**	**2000**	**2010**	**2020**	**2030**	**2040**	**2050**
		Most Likely	54	53	51	49	49	49
		High		58	56	54	54	54
Per Capita Outdoor Use (gpd)	Constant							
		Value	2.85	2.98	3.09	3.19	3.29	3.37
Medium Density								
Acreage	LogNormal (truncated)	Minimum		2,929	3,091	3,253	3,415	3,578
		Mean	2,767	2,981	3,195	3,409	3,623	3,838
		Maximum		3,151	3,536	3,920	4,305	4,689
		SD		298.1	319.5	340.9	362.3	383.8
Housing Density	Triangular	Low		16.4	16.38	16.36	16.34	16.33
		Most Likely	16.43	16.59	16.74	16.86	16.97	17.07
		High		16.7	16.91	17.09	17.23	17.35
Per Capita Indoor Use (gpd)	Triangular	Low		48	46	44	44	44
		Most Likely	54	53	51	49	49	49
		High		58	56	54	54	54
Per Capita Outdoor Use (gpd)	Constant							
		Value	2.85	2.83	2.81	2.8	2.78	2.77
High Density								
Acreage	LogNormal (truncated)	Minimum		94	95	96	97	99
		Mean	93	95	97	98	100	102
		Maximum		98	103	108	113	118
		SD		9.5	9.7	9.8	10	10.2
Housing Density	Triangular	Low		24.97	25.13	25.3	25.45	25.61
		Most Likely	24.8	25.57	26.33	27.05	27.75	28.42
		High		25.71	26.54	27.29	27.97	28.59
Per Capita Indoor Use (gpd)	Triangular	Low		48	46	44	44	44
		Most Likely	54	53	51	49	49	49
		High		58	56	54	54	54

Table 11. Assigned Probability Distributions for Uncertainty Analysis								
			Parameter Values					
			Current	Estimated				
Simulation Variables	Distributions	Parameters	2000	2010	2020	2030	2040	2050
Per Capita Outdoor Use (gpd)	Constant							
		Value	2.85	2.76	2.68	2.61	2.55	2.49
Commercial								
Retail Acreage	LogNormal (truncated)	Low		5,774	6,440	7,105	7,771	8,436
		Most Likely	5,109	6,014	6,919	7,824	8,728	9,633
		High		6,699	8,289	9,879	11,469	13,059
		SD		601.4	691.9	782.4	872.8	963.3
Retail Water Use (gpd/acre)	Triangular	Low		612.9	606.6	600.3	594.0	587.7
		Most Likely	695	681	674	667	660	653
		High		749.1	741.4	733.7	726	718.3
Other Acreage	LogNormal (truncated)	Low		3,486	3,786	4,085	4,385	4,685
		Most Likely	3,186	3,588	3,989	4,391	4,792	5,193
		High		3,907	4,628	5,349	6,070	6,791
		SD		358.8	398.9	439.1	479.2	519.3

Table 11. Assigned Probability Distributions for Uncertainty Analysis								
			Parameter Values					
			Current	**Estimated**				
Simulation Variables	**Distributions**	**Parameters**	**2000**	**2010**	**2020**	**2030**	**2040**	**2050**
Other Water Use (gpd/acre)	Triangular	Low		2,286.9	2,263.5	2,240.1	2,216.7	2,193.3
		Most Likely	2,592	2,541	2,515	2,489	2,463	2,437
		High		2,795.1	2,766.5	2,737.9	2,709.3	2,680.7
Industrial								
Total Acreage	LogNormal (truncated)	Low		10,054	10,486	10,918	11,350	11,782
		Most Likely	9,623	10,399	11,175	11,951	12,727	13,503
		High		11,490	13,356	15,223	17,090	18,957
		SD		1,039.9	1,117.5	1,195.1	1,272.7	1,350.3
Total Water Use (gpd/acre)	Triangular	Low		989	960	935	919	905
		Most Likely	1,020	1,013	1,006	1,000	1,000	1,000
		High		1,109	1,185	1,252	1,316	1,372
Military								
Military Usage (mgd)	Constant	Value	4.03	4.01	4	3.98	3.97	3.96
Military Reserve (mgd)	Constant	Value	3	3	3	3	3	3
Unaccounted								
System Losses	Constant Percentage of RRSWG Demand	Value	6.3	8.2	10	10	10	10
Future RRSWG Demand	The simulated value is the sum of sector totals (including unaccounted).							

Per capita usage rates for each residential sector and housing density category are allowed to vary over time. According to the January 12 discussion with HDR, only the indoor components of residential per capita use are treated as uncertain, using triangular distributions. Indoor residential per capita usage rates vary around their most likely point estimates, plus or minus 5 gpd. The HDR report states that per capita rates among density categories are positively correlated, so that samplings of higher per capita rates in one density category are associated with higher rates in other categories. This is reasonable, given that weather conditions and other demographic characteristics of the residential sectors are not included within the projection methodology. The degree of correlation is not reported in the HDR study. However, the January 12 discussion with HDR indicated the use of a correlation coefficient of 0.9 for both residential sectors and all density categories.

Aside from the per capita rates of use, all other variables are sampled independently from the defined distributions. A total of 10,000 iterations are performed using Monte Carlo sampling from the defined distributions. Treated independently from all other sectors, the mean of the sampling distribution of 2050 single-family water use is reported as 28.8 mgd, higher than the point estimate of 27.3 mgd. The mean of the distribution of 2050 multifamily demands is reported as 12.45 mgd, which is also higher than the point estimate of 11.71. The skew of these distributions relative to the point estimates is generally a result of the skewed nature of the assumed distributions for population and acreage. In other words, the mathematical expectation (or mean) of the lognormal distributions will lie to the right of the most likely values derived from the REMI model, which were used to derive the point estimates.

Assumptions for Commercial and Industrial Demand Simulations

Water demand in commercial and industrial sectors is a simple product of developed acres and water use per acre. As shown in Table 11, log-normal distributions are assigned to acres devoted to retail uses, other commercial uses, and industrial uses (light plus heavy industry). Just as in the residential simulations, the acreage distributions are defined by the most likely point estimates of acres and standard deviations equal to 10 percent of the most likely estimates. The minimum and maximum possible values of acreage derived from the land use analysis and REMI market analysis are used to limit (or truncate) the range of possible values for sampling.

Water use per acre in the commercial sectors is assigned triangular distributions around the most likely per acre point estimates. The minima and maxima of the retail and other commercial categories are assigned to be ± 10 percent of the most likely water use per acre values.

Water use per acre in the industrial sector is also defined by a triangular distribution. The lower bound for water use per acre is defined by IWR “alternative” estimates. Meanwhile, the upper bounds of the distributions are assumed to widen according to expected higher use in targeted industries.

Sampling from these nonresidential sectors is independent, with no assumed correlation among per acre usage rates or developed acres. Based on a simulation of 10,000 trials, the mean value for 2050 commercial water use is reported as 19.4 mgd, which is slightly greater than the point estimate of 18.95 mgd. The mean value for 2050 industrial use is reported as 15.0 mgd, which is also greater than the corresponding point estimate of 13.5 mgd. The mean values for demand are higher than the point estimates, because the distributions of future developed acres are skewed such that the mean value of acres will exceed the most likely value.

Simulation of Total Demands

From review of the HDR report, it is implied that total water use is simulated as a sum of independent samplings from residential, commercial, and industrial sectors. Military use is held roughly constant and added to the sum of residential, commercial, and industrial use. Unaccounted use is then added proportionally to the sum of water use in all of the defined sectors. Unaccounted use is assumed to grow from about 6 percent to 10 percent by the end of the time horizon. Unaccounted use is treated as certain, in that it is not allowed to vary in any single forecast year. The sampling distribution for total demand in 2050 is relatively symmetric and narrow with a reported mean of 90.4 mgd. This exceeds the point estimate for 2050 total demand of 87.14 mgd.

Verification of Demand Simulations

In preparation for constructing a Monte Carlo simulation of demand for the IWR Panel, attempts were made to replicate the outcomes of the HDR simulation of demands. Generally, given the information provided in the HDR report and discussion with HDR personnel, the distributions of total demand and demand for each water use sector were reproduced for 2050 to the extent that their respective means matched very closely those illustrated in the HDR report. This required the following adjustments to the distributional assumptions listed in Table 11:

- The lognormal distributions for residential acreage were replaced with triangular distributions defined by the low, most likely, and high values reported in Table 11. It is likely that this was an oversight in the HDR analysis, and does not have an appreciable nor crucial impact on the demand estimates.
- Unaccounted water (UAW) is treated as a percent of metered use and not of total production. UAW is typically calculated in the following way:

  $$Q_{UAW} = Q_{metered} * (p/(1-p))$$

  where p is fraction unaccounted. In order to replicate the total demand distribution, it was necessary to specify UAW as: $Q_{UAW} = Q_{metered} * p$. UAW is calculated correctly in the text of the HDR report from point estimates of demand. Therefore, this is believed to represent a small error in HDR's development of its simulation model.

Table 12 provides the replicated water demand estimates for the forecast period. The cumulative distribution of total 2050 demand (as represented by the percentile values) mimics the distribution provided in the HDR report with considerable precision, which supports the adjustments to the simulation noted above. Since equivalent data are not reported in the HDR report, the distributions for demand reported in Table 12 for all other sectors and years have no direct basis for comparison/verification.

Note on Sensitivity of Outcomes to Population Projections

Population projections play a significant role in the future water demand estimates. The high, medium, and low growth scenarios produced by the REMI model are used to create distributions on projected population. The implicit assumption of annually compounding growth creates more possibilities of future population exceeding the most likely estimates. In other words, the distribution of future population is skewed to the right. As a result, distributions for future acreage estimates also show an extended right-hand tail.

Another way to express uncertainty in population is to create a probability distribution for annual rate of population growth using the implied REMI annual growth rates. Further, and as the time series of historic population shows, annual growth can be allowed to vary independently from year to year. To analyze the sensitivity of the assumptions for population growth, alternative probability distributions were formed based on the following assumptions:

1. Annual percentage growth in population is defined by a triangular distribution with the following parameters implied from the REMI results: High = 1.26 percent, Low = 0.41 percent, most likely = 0.71 percent.
2. Annual growth rates are independent in time. The annual increment in population in one year is not correlated with the annual increment in population in any other year.

As shown in Table 13, treating growth in population in this way produces different results. Namely, by 2050, the mean of the sampling distribution for population is higher than the most likely estimate reported by HDR, but the range of uncertainty is much smaller.

These results imply that mean residential demand would be higher than reported in the HDR report and that the distribution encompassing the mean use would be narrower. Both of these impacts could affect the determination of the range of possible deficits. However, because adoption of this approach would require a fundamental change in the use of the REMI estimates of population and subsequent acreage, these results are provided only to demonstrate the potential sensitivity of demand estimates to compounding growth rates.

Table 12. Verification Trial of Simulated Demands
(based on 10,000 iterations; water use values expressed in mgd)

	Commercial					Industrial					Multifamily					Single-Family					Total Demand				
Year	2010	2020	2030	2040	2050	2010	2020	2030	2040	2050	2010	2020	2030	2040	2050	2010	2020	2030	2040	2050	2010	2020	2030	2040	2050
Minimum	11.91	12.95	14.02	15.07	16.08	9.96	10.18	10.42	10.56	10.99	8.87	9.08	9.09	9.46	10.12	18.34	19.57	20.74	22.45	23.68	62.71	67.63	71.03	75.85	80.23
Maximum	15.73	18.18	20.24	22.58	24.73	12.69	15.53	18.80	20.67	22.82	11.29	12.07	12.94	14.29	15.80	22.65	26.16	29.37	32.34	35.86	71.67	81.89	88.52	98.82	105.22
Mean	13.56	15.19	16.67	18.06	19.40	11.09	12.15	13.08	14.04	15.00	10.01	10.46	10.85	11.63	12.41	20.40	22.42	24.61	26.87	28.91	67.16	73.96	79.40	85.32	90.95
Std Dev.	0.54	0.79	0.99	1.16	1.31	0.50	0.94	1.29	1.61	1.88	0.38	0.47	0.57	0.68	0.80	0.69	0.95	1.24	1.52	1.79	1.34	1.93	2.49	2.99	3.50
Variance	0.29	0.62	0.98	1.35	1.72	0.25	0.88	1.66	2.60	3.54	0.15	0.22	0.33	0.46	0.64	0.48	0.90	1.53	2.32	3.22	1.81	3.73	6.22	8.94	12.28
Skewness	0.12	0.20	0.35	0.44	0.46	0.25	0.47	0.56	0.58	0.58	0.06	0.10	0.17	0.23	0.25	0.07	0.16	0.20	0.22	0.26	0.04	0.10	0.16	0.18	0.25
Kurtosis	2.74	2.78	2.86	3.00	3.06	2.44	2.83	3.13	3.14	3.15	2.58	2.74	2.82	2.88	2.84	2.66	2.84	2.84	2.83	2.87	2.73	2.87	2.94	2.89	3.02
Percentiles																									
5%	12.70	13.95	15.16	16.34	17.45	10.33	10.78	11.23	11.72	12.32	9.38	9.69	9.93	10.56	11.17	19.27	20.89	22.64	24.46	26.12	64.98	70.80	75.42	80.53	85.45
10%	12.87	14.19	15.43	16.64	17.80	10.45	10.99	11.51	12.09	12.75	9.50	9.85	10.11	10.77	11.40	19.49	21.22	23.02	24.93	26.66	65.43	71.48	76.27	81.50	86.58
15%	12.99	14.36	15.64	16.87	18.05	10.55	11.15	11.73	12.37	13.06	9.59	9.96	10.25	10.93	11.58	19.66	21.44	23.30	25.26	27.04	65.76	71.94	76.80	82.20	87.30
20%	13.09	14.50	15.81	17.05	18.26	10.63	11.30	11.94	12.62	13.34	9.67	10.05	10.35	11.05	11.71	19.80	21.62	23.54	25.53	27.37	66.01	72.31	77.28	82.78	87.89
25%	13.18	14.62	15.95	17.23	18.43	10.71	11.43	12.12	12.84	13.60	9.73	10.13	10.44	11.14	11.84	19.91	21.76	23.74	25.80	27.64	66.22	72.64	77.68	83.23	88.44
30%	13.26	14.74	16.08	17.37	18.61	10.78	11.57	12.29	13.05	13.83	9.79	10.20	10.53	11.24	11.96	20.02	21.90	23.91	26.01	27.89	66.42	72.90	78.01	83.67	88.98
35%	13.33	14.86	16.21	17.53	18.79	10.86	11.70	12.45	13.26	14.06	9.85	10.26	10.61	11.34	12.06	20.12	22.02	24.09	26.22	28.14	66.61	73.19	78.33	84.09	89.46
40%	13.40	14.97	16.34	17.67	18.97	10.92	11.82	12.62	13.46	14.31	9.90	10.33	10.68	11.43	12.17	20.22	22.15	24.25	26.42	28.37	66.78	73.43	78.69	84.49	89.93
45%	13.48	15.07	16.46	17.80	19.12	10.99	11.95	12.79	13.66	14.56	9.95	10.40	10.76	11.51	12.26	20.31	22.26	24.40	26.62	28.59	66.97	73.68	79.00	84.84	90.40
50%	13.55	15.17	16.59	17.95	19.29	11.07	12.07	12.94	13.88	14.79	10.00	10.45	10.84	11.59	12.36	20.40	22.39	24.56	26.82	28.81	67.14	73.91	79.34	85.20	90.84
55%	13.62	15.26	16.72	18.09	19.45	11.14	12.19	13.11	14.08	15.04	10.06	10.52	10.91	11.68	12.47	20.48	22.51	24.72	27.02	29.04	67.32	74.15	79.65	85.58	91.28
60%	13.69	15.37	16.86	18.25	19.61	11.21	12.32	13.30	14.30	15.28	10.11	10.58	10.98	11.77	12.58	20.57	22.63	24.88	27.18	29.29	67.50	74.42	79.97	85.96	91.75
65%	13.76	15.48	17.01	18.41	19.78	11.29	12.46	13.48	14.52	15.53	10.16	10.64	11.06	11.86	12.70	20.67	22.76	25.05	27.41	29.56	67.69	74.67	80.32	86.41	92.20
70%	13.85	15.60	17.16	18.59	19.99	11.37	12.61	13.67	14.76	15.84	10.21	10.71	11.15	11.96	12.82	20.78	22.91	25.23	27.64	29.82	67.89	74.94	80.68	86.85	92.71
75%	13.93	15.73	17.32	18.78	20.22	11.45	12.78	13.89	15.05	16.18	10.27	10.78	11.24	12.07	12.95	20.88	23.06	25.44	27.86	30.12	68.10	75.25	81.07	87.29	93.23
80%	14.02	15.88	17.50	19.03	20.49	11.54	12.96	14.16	15.37	16.57	10.34	10.86	11.33	12.20	13.09	21.01	23.23	25.65	28.14	30.46	68.34	75.58	81.52	87.84	93.85
85%	14.13	16.04	17.71	19.31	20.79	11.64	13.16	14.44	15.76	17.01	10.42	10.96	11.45	12.34	13.26	21.14	23.43	25.92	28.47	30.81	68.61	76.01	82.01	88.45	94.56
90%	14.27	16.24	17.99	19.64	21.19	11.78	13.44	14.83	16.27	17.57	10.52	11.08	11.60	12.54	13.46	21.32	23.68	26.25	28.88	31.29	68.93	76.48	82.65	89.27	95.49
95%	14.47	16.56	18.41	20.15	21.77	11.96	13.83	15.40	16.98	18.43	10.65	11.25	11.82	12.81	13.78	21.56	24.03	26.72	29.50	32.04	69.38	77.22	83.61	90.42	96.94

Table 13. Comparison of distributions of 2050 population

	Simulated Population*	HDR/REMI Population
Min	651543	562455
5%	665780	
25%	673653	
Mean	679465	644049
75%	685061	
95%	693769.3	
Max	713279	845083
Range	61736	282628

*Based on 5,000 iterations

Principal Findings and Conclusions on Demand

The major assumptions in the evaluation of the water demand forecast prepared by HDR are reasonable. The evaluation of the water demand forecast prepared by HDR shows no glaring implausible assumptions. The adoption of the REMI growth model appears to remedy some of the concerns about demographic and economic growth expressed during review of the FEIS. There are several items that may summarize the key points of the evaluation:

1. The demand forecasts presented in the HDR report are better than typical industry practice with respect to treatment of uncertainty around point estimates. However, the general land-use based forecasting approach does not address several other factors (such as marginal price of water and rate structure, household income, or composition of commercial and industrial sectors) that are likely to influence the aggregate unit rates of sectoral water use in the future. Specification of a larger number of causal influences within a predictive model would allow for a more explicit and meaningful treatment of uncertainty in per capita and total demands.

2. Similar to the Final EIS demand projections, the forecasts prepared in the HDR report depend primarily on projections of population. The point population projections were verified as being reasonable in comparison to the historical rates of water use; however, the HDR estimates of future population are higher than previous estimates and can be considered optimistic relative to the federal projections for the State of Virginia. The latter assume a declining annual increment in total population while the VEC and HDR projections rely on a constant annual increments in population during the 50-year forecasting period.)

3. The 2040 point (termed “most likely”) estimates of future water use are about 16 mgd lower than demands presented in the FEIS, but about 7 mgd higher than the IWR Panel “center of opinion” estimate.

4. From year 2030 onward, it is assumed that 100 percent of the population is served by the RRWSG. This is a change with respect to the FEIS, which assumed about 94 percent served in 2040. At assumed residential per capita rates of 60.6, this translates into an increase of 2.2 mgd relative to having only 94 percent of 2040 population served, everything else held constant.

5. Based on the review of various details of system management, the current estimate of 6.3 percent UAW is plausible and well supported. HDR proposes that UAW will increase to 10 percent by the year 2030, noting that 10 percent is the "statewide and regional utility norm." The IWR Panel previously supported the 10% estimate. In the succeeding months, new reports have provided additional information on the question of UAW and water losses in general. It is now possible to assemble a more detailed picture of water losses and of the assumptions used by HDR in estimating capacity requirements. Consequently, the Panel reduced its estimate of UAW to 8%.

6. The HDR report adds a military reserve of 3 mgd as a contingency for defense mobilization and buildup. We accept this reserve capacity as part of prudent planning given the large military presence in the region, but the justification for the assumed quantity is based on some historical information from the World War II period, which may not be relevant for estimating mobilization needs today.

7. The forecast of commercial water demands assumes growth in commercial acreage that exceeds both the growth in population and commercial employment. If the rate of growth of acreage in the commercial sector is assumed to equal the rate of growth of population, then commercial demand in 2040 would be 2.05 mgd lower than referenced in the HDR report.

8. The assumed residential per capita usage rate for 2040 is 0.9 gpcpd higher in comparison to the IWR Panel "center of opinion" estimate. This difference contributes only 0.55 mgd to 2040 demand.

9. The benefit-cost analysis of water conservation alternatives does not include an estimate for possible savings in deferred or avoided capital costs of water infrastructure. Given the gradual increase in demand, the actual date to which a capital costs would be deferred is uncertain and it would be necessary to discount the benefits. It may be that additional savings particularly in the commercial and industrial sectors can be justified, but not without individual user audits as proposed in the listed conservation measures.

10. The Panel was able to replicate HDR's sampling distributions for future water demand with only minor discrepancies. Replication of these distributions confirms that the point estimates invariably fall below the mean values of each distribution. For the distribution of total demands, the difference is 4.2 percent of the point estimate. The primary reason for this lies in asymmetric shape of the distributions for population and acreage.

Supply

This review marked the first time the Panel reviewed the supply analysis in depth. The Panel generally found the supply analysis sound and reasonable. The Panel reviewed and accepted the point estimates of groundwater yields, but modified some of the probability distributions describing the likely future yields of existing groundwater sources to reflect our sense that the groundwater yields are sustainable. The Panel reviewed and generally accepted the estimates of surface water safe yield, but did not agree with the method of factoring surface water availability into the overall risk of water shortages. The Panel's estimate of the overall treated water safe yield of the system was essentially identical to the estimates reported by HDR.

The Panel also reviewed the "Reevaluation of Critical Drought Condition and Safe Yield of Existing System, June 2000, by Camp Dresser & McKee" and the use of its conclusions in the HDR Report. The CD&M report explains how the synthesized 162-year monthly streamflow record used in the safe yield analysis was developed. We believe the 20th century portion of that streamflow set can be used to estimate risks of shortages; the lowest multi-year flows probably represent a drought that could be expected once every 80 to 100 years. The Panel accepted the 19h century portion of the flow record for the simulation of an extraordinary drought, but believes the recurrence interval of such a drought is about one in 1,000 years.

Other Supply Sources

The HDR report does not address the possible use of excess Norfolk supply. This is addressed in "Water Supply Alternatives Cost Projections Notebook" developed by Malcolm Pirnie for the RRWSG. That report estimates the construction and operating costs of five water supply alternatives including the King William Reservoir ($525.8 million over 50 years) and Norfolk Raw Water Surplus ($744.9 million for the same period). The Panel did attempt a technical review of the cost estimate for the Norfolk water, since the issue of the availability of that water has not been settled.

According to the Hampton Roads Daily Press, the James City County Board of Supervisors voted on June 28, 2000 to go ahead with plans for a plant that would desalinate brackish groundwater. The newspaper reported that the project is estimated to cost $20 million and will provide 6 MGD of water in five years. The HDR report does not include the safe yield from a proposed James City County groundwater desalination plant, but concludes, "It may be several years before the required testing and permitting has been competed to confirm the regulatory and cost feasibility of this project. It is quite likely that a future County Board of Supervisors would vote to approve funding for the design and construction of the project." In a November 29, 2000 letter to COL Carroll, Newport News criticized IWR for relying on news reports describing the approval. The city noted that the implementation process had just begun and that construction had not been authorized, that there were several administrative hurdles yet to be cleared, that James City County was negotiating an agreement for an intertie with Newport News, and that some of the yield of the new project would replace rather than supplement freshwater yields, providing a net increase of less than 2 mgd. The city provided a copy of a memorandum from Larry M. Foster, the General Manager, James City Service Authority to the Board of Directors. In that memo, Mr. Foster references a study that indicated there is sufficient water supply to meet the region's (apparently the County's) needs for the next 10-15 years. He writes that the Water Master Plan provides that the County will begin the process of permitting and building a groundwater desalination facility on July 1, 2000 if the King William Reservoir project has not received a permit form the Corps of Engineers. Newport News also attached a letter from the Virginia Department of Health to Mr. Foster dated August 1999 which states the Department of Health position on the desalination plant: "We also support and concur with the construction of a 4-6 mgd groundwater desalination facility." The Panel accepts that the plant has not been built yet, and that it might not be, but none of the evidence supplied by Newport News makes it seem less likely than any other component of the future planning scenario. The Panel analyzed water shortage risks with and without this water source so the sensitivity of the risk to the realization of this new source could be seen. Our review of the freshwater aquifer does not support the conclusion that the aquifer is stressed at the current pumping rates, and nothing in the material provided by James City County indicates that other sources would be retired.

The Panel raises the possibility of conjunctive use of groundwater, but does not pretend to know if it is a viable option.

Safe Yield

Table 14 lists the HDR estimates of safe yields of treated water that can be expected from all public water sources in the RRWSG service area, and the surface water portion of that yield. The last line of the table shows the Panel's estimate of the surface water safe yield. Our analysis of safe yield begins on page 54.

Table 14. Safe Yield Estimates
Point estimates in HDR Report for each system component
IWR estimate for surface water component

System	Raw Water Safe Yield (mgd)	Evaporation	Seepage	Treatment	Treated Water Safe Yield (mgd)
Newport News					
Surface Water	54.8	Included left	4.0	0.6	51.1
Brackish Groundwater					5.7
Subtotal					56.8
Williamsburg					
Waller Mill Reservoir		Included right	0.2	0.1	2.6
Augmentation well					0.68
Subtotal					3.3
James City County*					
29 freshwater wells					4.9
Brackish Groundwater					0
York County*					
5 wells					0.6
Big Bethel Reservoir					2
Cheatham Annex					0.1
System totals					67.7
RRWSG Surface water only					56.5
IWR Surface Water		Evaporation, seepage and treatment losses included in 56.7 estimate			56.7

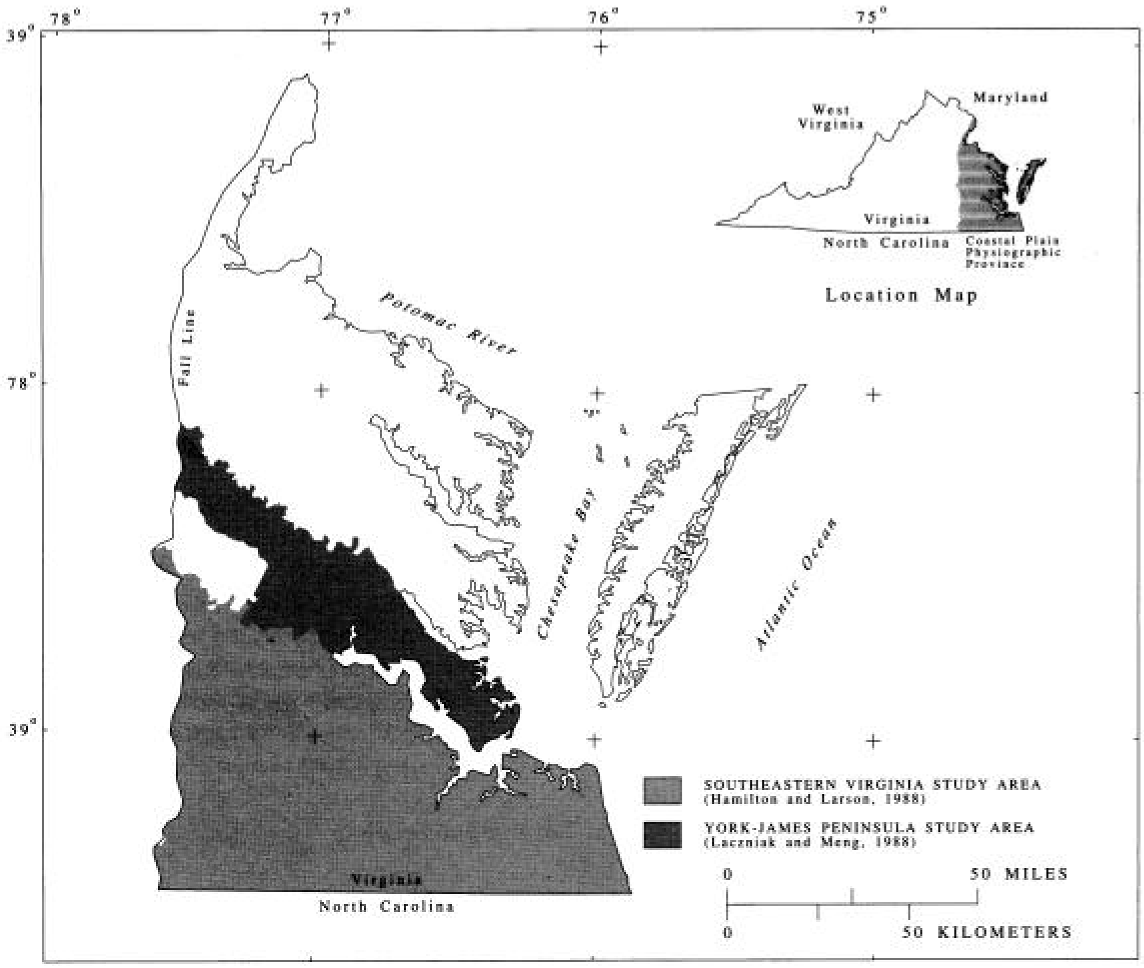

Figure 4. Groundwater Study Area

Groundwater

Four sources of groundwater are included in the water supply systems for the Regional Raw Water Supply Group (RRWSG). These are 1) the Newport News brackish groundwater wells, 2) the Williamsburg augmentation well, 3) the James City Service Authority wells, and 4) the York County wells. These wells extract groundwater from several different aquifers beneath the York-James Peninsula. The wells that are included in the James City Service Authority and York County sources extract water from the Chickahominy-Piney Point aquifer. This is a relatively shallow aquifer that has been shown to be particularly vulnerable to excessive drawdown and reduced yields (Lazniak and Meng, 1988). Because of this vulnerability, the HDR analysis assumes that the yields from the James City and York County wells may decrease in the future due to future additional groundwater development.

It is important to note that HDR does not suggest that the current yields from the Chickahominy-Piney Point aquifer are unsustainable. Rather, they have assumed that additional demands will be placed on this aquifer and that these additional demands may result in decreased yields from the existing, permitted wells. The HDR analysis assumes that groundwater wells completed in deeper aquifers are less vulnerable to impacts from future groundwater development on the York-James Peninsula. The potential impacts of future groundwater development on yields from wells completed in the Chickahominy-Piney Point aquifer are incorporated in the HDR analysis through probability distribution functions. Yields from wells that are completed in deeper aquifers are assumed to be certain and constant.

The James City Service Authority has a current yield from groundwater equal to 4.9 mgd. Approximately 25% of this (1.3 mgd) is derived from deeper aquifers and is assumed to be certain. The remaining 75% of the yield (3.6 mgd) is derived from the Chickahominy-Piney Point aquifer and is assumed to be uncertain. A triangular probability distribution function is used to describe this uncertainty, as shown on Figure 5-10, page 5-22 in the HDR report. The current yield (3.6 mgd) is assumed to be both the maximum value and the most likely value for this distribution. The minimum value for the yield from the Chickahominy-Piney Point aquifer is assumed to be 1.0 mgd.

The groundwater yield for the York County system is all derived from the Chickahominy-Piney Point aquifer and is assumed to be uncertain. A triangular probability distribution function is used to describe this uncertainty, as shown on Figure 5-10, page 5-22 in the HDR report. The current yield (0.63 mgd) is assumed to be both the maximum value and the most likely value for this distribution. The minimum value for the yield from the Chickahominy-Piney Point aquifer is assumed to be zero for the York County system.

Yields from groundwater wells in the Newport News and Williamsburg systems are assumed to be certain, constant, and equal to the current yields. The current groundwater yield for the Newport News system is 5.7 mgd. The current yield for the Williamsburg system is 0.68 mgd.

Summary of conclusions from the Malcolm Pirnie report.

The Malcolm Pirnie report describes the results of computer modeling activities aimed at assessing the availability of groundwater in the Chickahominy-Piney Point aquifer. The groundwater model used in their study is based on a model originally developed by the USGS during the 1980's and 1990's (Meng and Harsh,1988; Harsh and Lazniak, 1990; Focazio and Samsel, 1993; McFarland, 1998). The model is used to calculate water levels in the various aquifers that comprise the groundwater flow system on the York-James Peninsula. The area include in the model, which is shown on Figure 4, encompasses the Virginia Coastal Plain. The boundaries for the model include the Potomac River on the north, the Chesapeake Bay and Atlantic Ocean on the east, North Carolina on the south, and the Fall Line on the west. The USGS used the model to simulate the impacts of groundwater development from 1890 through 1986 (Focazio and Samsel, 1993).

The original USGS model was modified in the Malcolm Pirnie study to provide higher resolution in the vicinity of the York-James Peninsula. The same spatial extent is used in the Malcolm Pirnie model - only the grid spacing is changed. The Malcolm Pirnie model also includes additional groundwater extraction for the time period from 1986 through 1998. The original model included a total groundwater withdrawal of 105 mgd over the model area (McFarland, 1998). In the Malcolm Pirnie model, an additional 13.7 mgd of groundwater withdrawal is added to reflect increases in what are termed "regional groundwater withdrawals." An additional 1 mgd is also added to account for individual residential wells within James City County. Other local groundwater withdrawals were also included in the Malcolm Pirnie model, but it is not clear based on the information in the report how much additional withdrawal is added. The total groundwater extraction from the Chickahominy-Piney Point aquifer is assumed equal to 5 mgd in the Malcolm Pirnie model.

The model is used to simulate groundwater levels between 1998 and 2020. It is assumed within the model that the groundwater withdrawal during this period is constant. The results presented in the report include calculated water levels within the Chickahominy-Piney Point aquifer along a transect through the York-James Peninsula. Based on these simulations, the Malcolm Pirnie report concludes that under current withdrawal conditions, there is adequate groundwater available in the Chickahominy-Piney Point aquifer through 2020.

The model was also used to evaluate the impacts of additional pumping within the Chickahominy-Piney Point aquifer. Pumping rates at existing wells were increased by 40% so that the total groundwater extraction from the Chickahominy-Piney Point aquifer increased from 5 mgd to 7 mgd. With this additional groundwater extraction, the drawdown in water levels within the Chickahominy-Piney Point aquifer approached the criterion set by the Virginia Department of Environmental Quality. The aquifer was not de-watered under this scenario - the water levels remained above the top of the aquifer.

Aquifer de-watering did not occur until the groundwater extraction within the Chickahominy-Piney Point aquifer was increased by 6 mgd (from 5 mgd to 11mgd).

Why estimates for groundwater yield given in the Malcolm Pirnie report may be low

The USGS model was re-calibrated in the Malcolm Pirnie study. This re-calibration involved reducing the leakance values for the confining units of several aquifers. These leakance values control how easily water moves in a vertical direction between aquifers. The leakance factors were reduced by a factor of two in the Malcolm Pirnie study. Smaller leakance values result in more drawdown within aquifers that include extraction wells. This is because less water flows into the pumped aquifers to replenish the water that is extracted.

The Malcolm Pirnie report does not provide sensitivity studies that could be used to evaluate how sensitive the water level predictions are to changes in the leakance values. The changes are justified in the report based on a set of calibration data from two wells. The calculated water levels are generally below the observed water levels for most times at these two calibration points (calculated drawdowns are larger than observed drawdowns). The effects of adjusting other input parameters are not discussed. The Malcolm Pirnie report indicates that only model storage and leakance values were changed in the calibration (page 7), but no information is given on what storage values were used in the final simulations.

The Malcolm Pirnie model evaluates three scenarios involving increased groundwater extraction. It is assumed within these scenarios that all new groundwater withdrawals will be from the same locations as the current withdrawals. The total groundwater extraction from existing wells within the Chickahominy-Piney Point aquifer is assumed to equal 7, 9, and 11 mgd in these three scenarios. This represents increases in pumping rates of 40%, 80%, and 120% above the base case estimate of 5 mgd. If additional groundwater extraction is derived from unregulated users, as is assumed in the HDR report, then it is unlikely that these extractions would be from the same locations as the current wells. Less drawdown would occur within the Chickahominy-Piney Point aquifer if the withdrawals were assumed to be more diffuse.

USGS studies, other sources of groundwater, and related issues

Studies completed by the USGS have shown that the Chickahominy-Piney Point aquifer is the most sensitive aquifer on the York-James Peninsula in terms of impacts due to increased groundwater withdrawals (Lazniak and Meng, 1988). These studies have also shown that deeper aquifers are less vulnerable to excessive drawdowns. The study by Lazniak and Meng is particularly relevant to the HDR and Malcolm Pirnie studies because it focuses specifically on ground-water resources of the York-James Peninsula. The study area is shown in Figure 4. The model used in the Lazniak and Meng work was derived from the same USGS studies and models used in the Malcolm Pirnie analysis.

Lazniak and Meng considered several scenarios for future groundwater development on the York-James Peninsula. One scenario involved across-the-board increases in pumping rates at all existing wells. This scenario is similar to the scenarios considered in the Malcolm Pirnie report. The USGS study showed that this approach resulted in significantly higher drawdowns (lower water levels) in the Chickahominy-Piney Point aquifer than what would occur with more "strategic" pumping locations. The model results from the Lazniak and Meng study suggest that groundwater extraction on the York-James Peninsula could increase by 65% (from 38 to 68 mgd) without causing excessive drawdowns in the Chickahominy-Piney Point aquifer. This assumes that groundwater development occurs in both the Chickahominy-Piney Point aquifers and deeper aquifers. It should be noted that the water quality in deeper aquifers may require treatment similar to what is accomplished with the Newport News brackish groundwater system.

Regulations have been developed to control additional groundwater resource development in this area (VAC 25-600-20). The State of Virginia can regulate all groundwater extraction from designated ground water management areas. The Eastern Virginia Ground Water Management Area includes the York-James Peninsula. The HDR conclusion that groundwater yields may drop due to unregulated pumping does not explicitly recognize institutional controls that could prevent this.

Recent changes in Virginia regulations require that groundwater permits be reviewed every 10 years (USGS, 1999). It is conceivable that groundwater use by industry and agriculture could decrease in the future and these rights could be transferred to the public sector.

The analyses in both the Malcolm Pirnie and the USGS studies do not explicitly consider the impact of groundwater extraction on stream flow. For relatively shallow aquifers in the western part of the study area, additional groundwater extraction may result in reduced streamflow. This would be less important for deeper aquifers and for wells in the eastern part of the study area.

Surface Water

There are seven reservoirs in the RRWSG area; Big Bethel, Waller Mill and the five reservoirs owned by the city of Newport News. All seven rely at least to some extent on the flows from the Chickahominy River. The inflow to the Waller Mill Reservoir can be supplemented by pumping at up to 0.68 mgd from a well. Both Waller Mill and Big Bethel can receive raw water from Newport News. Taken together, these reservoirs have a gross storage capacity of almost 15 billion gallons. These reservoirs produce a safe yield of about 56 mgd, a fourth of the average inflow to them, based on the assumptions that the lower third of the reservoir volume is unusable and that water use would continue without curtailment until the reservoirs were depleted.

Streamflow

Typically, the drought used to test the water system is the worst drought on record. In the Final EIS, Newport News estimated the safe yield of its system using the 1930's drought. IWR (October 2000) advised that the region could expect more severe droughts, and recommended that the system should be tested accordingly. In these reports, the system is tested with a credible simulation of an 1850's drought that reduces the system yield substantially. The Panel estimated safe yield using 1920-1999 flows, but also analyzed the likelihood and consequences of the 1850s drought. Our analysis of the 1850s drought is reported starting on page 46.

The CD&M Reevaluation study extended measured 1942-1999 streamflows on the Chickahominy River to cover the period of 1838-1999. The Panel applauds the effort to extend the data to as long of record as possible. By evaluating a longer streamflow record, a better understanding of the return period of droughts can be obtained, and the reaction of the system to extraordinary droughts can be considered.

Previous Studies.

The safe yield of the Newport News system has been estimated in several previous studies. The estimates from different studies are not directly comparable because data and assumptions varied from study to study. 1980s studies assumed 10-11% dead storage; that would produce a larger estimate of safe yield that the current studies, which are based on 33% dead storage. But the older studies also assumed a net evaporation of 27-29 inches per year while treating rainfall on the reservoir surface as if it were falling on the adjacent land. This would underestimate yield. The latest studies remove the reservoir surface area from the local drainage area, which would slightly reduce local inflows, and algebraically combine evaporation and rainfall on the reservoir surface, using an estimated net evaporation of 8.9 inches per year. The net effect would increase the estimate of safe yield.

Each study used slightly different streamflow data. The only directly measured streamflow used is from a gage on the Chickahominy River upstream of Walkers Dam where water is pumped into the reservoir system. Since the 1980s, additional flow records have raised the long-term average slightly. Flows at Walkers Dam were estimated using a ratio of drainage areas at the gage and the dam. Local inflows were estimated in different ways, usually including a drainage area ratio and portions of the flow records from one or more nearby streams. Raw water safe yields from these studies varied between 57 and 57.8 mgd. The latest study is based on a new, extended streamflow record. The Panel reviewed this work to judge its suitability for an assessment of the safe yield of the system and its relevance as a tool for characterizing droughts that might occur but are much more severe than any from the relatively short period of measured streamflow.

Historic Rainfall Records

Because the gauged streamflow data are limited, rainfall data are used to extend the record to periods prior to 1942. There are a number of challenges in using rainfall data to extend streamflow records. A number of approaches exist, but they can be summarized as statistical models and physically based models. Statistical models use regression techniques to relate rainfall to runoff through a series of correlation coefficients. Physically based models attempt to track the movement of water through portions of the hydrologic cycle. Examples of such models include the Stanford Watershed Model (Crawford and Linsley, 1966) and more current models such as the Distributed Hydrology Soil Vegetation Model (DHSVM) and the Variable Infiltration Capacity Model (VIC) (Liang, et. al., 1994, Wood, et. al., 1992, Wigmosta, et. al, 1994). It would have been preferable for the streamflow records to have been extended using a model such as DHSVM, with rainfall and temperature as the driving parameters. Such physically based models are typically superior to regression models in more hydrologically complex settings.

The precipitation measurements that form the basis for the synthesized streamflow extend into the 1830's. Average precipitation during the 19th century period is markedly less than the more recent records. Gages of that early period are now known to underestimate precipitation because of the lack of correction for evaporation as well as poor siting, suggesting the possibility of a downward bias in the synthesized record. Although the panel has serious doubts about the accuracy of the early numbers, the real question is whether the indicated drought event could happen. The National Drought Atlas is the most authoritative source for estimating the severity and duration of droughts. One of the key findings of the Atlas researchers is that there is a regional ratio of drought precipitation volumes to mean and median precipitation volumes. Nearby stations may have different means, but the estimated ratio of the fifty-year drought of a given duration to the mean precipitation for the same duration and starting month will be the same. The minimum five year precipitation in the constructed record used by CD&M is 146 inches; the mean is about 211; the ratio of the two is about 70%. Using that ratio and the Atlas distributions for this region, the frequency of this drought can be estimated at about 1 in 250 years, which is not surprising given the 162-year length of the record. However, this is the expected frequency of the precipitation amount, not the streamflow that was generated from these data.

Synthesized Streamflow Record

Given that a statistical model was used, it useful to note some of the challenges involved in using such a model. Many of these challenges are similar to those encountered when extending short streamflow records with longer streamflow records. In this setting, without a sufficiently long, nearby gauged stream, rainfall records must be used as a surrogate for streamflow. A number of important papers were written on the subject of streamflows extension in the 1980s, including those by Hirsch (1979, 1982) (the current Chief Hydrologist of the USGS) and Vogel and Stedinger (1985). In these papers, a number of conceptual approaches to extending data are addressed, in addition to specific techniques for minimizing the biases introduced when using log regression techniques.

The quality of extended records is impacted by several issues, including: 1) the length of overlap between the short record and the longer record to be used for extension, 2) degree of correlation between the two records, 3) the extent to which the correlation is impacted by extreme events, and 4) the manner in which the data are extended. The length of the overlap is very important. If there is not sufficient overlap between the two records, no correlation between the sites can be accurately calculated, even if one exists. Because of the spatially varying nature of rainfalls (in particular) and streamflows (to a lesser degree), two records may not well correlated, even if they are adjacent. If a low level of correlation exists between to sites, then the quality of data extended will not be good. In general, the further the distance between the two sites,

Often the factors that cause drought events result in responses in streamflows that are not similar to the responses that occur in more typical events. For instance, during periods of very low rainfall, streamflows may be driven by groundwater rather than surface responses. If the behavior of groundwater in two basins is not similar, then streamflows in the two basins could be highly correlated during normal or high flow events and much less correlated during drought events.

Finally, the precise manner in which records are extended can have a significant impact on the values of the extended data. Hirsch (1979, 1982) and Vogel and Stedinger (1984) have demonstrated that the specific statistical extension technique does play a large role in the quality of the record produced. Several of the basic concepts and concerns identified in these papers were apparently not considered in the CDM report. These include not using seasonal time-steps for the regression equations rather than a monthly time-step and maintaining the statistics of the original data rather than their log-transformed statistics.

Probability of Droughts

The worst five-year period in the extended record contained about 35% of the average streamflow. According to the Atlas, even the 1000-year return interval drought would still provide about 50% of average rainfall. Streamflow and runoff are not well correlated in the short term, but the correlation should improve for several year periods.

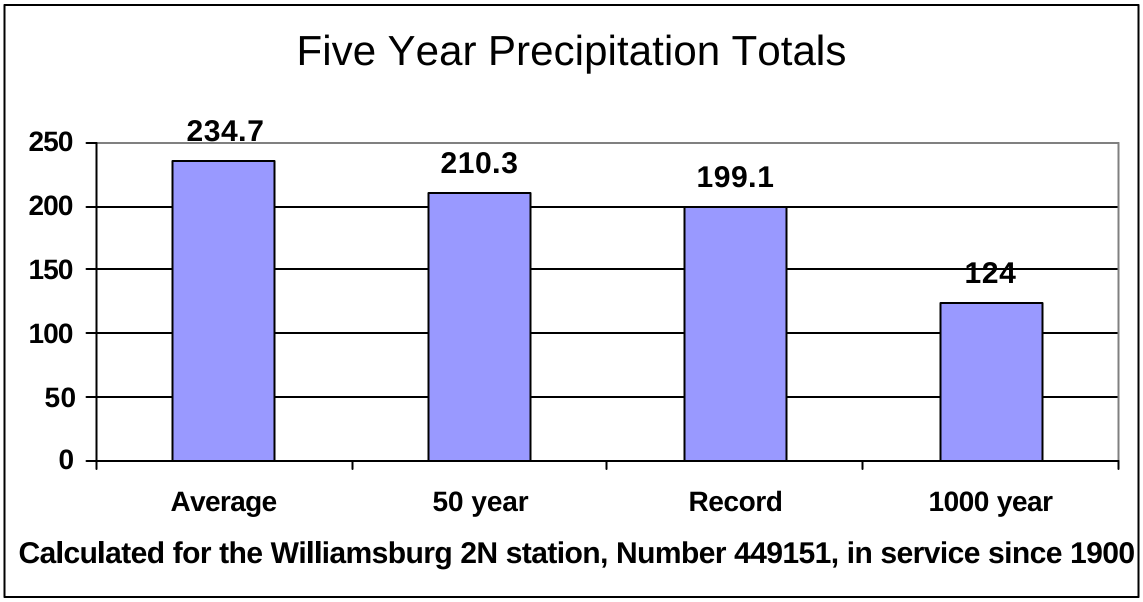

Figure 5. National Drought Atlas statistics for five-year precipitation volumes

The Panel compared measured precipitation and streamflow from 1942-1999, using the Chickahominy gauge and the 1942-1999 portion of the weighted precipitation record used by CD&M in the development of the new streamflow dataset.

The figure on the next page shows the ratio of the volume of precipitation in five-years periods (drainage area time precipitation depth) versus the gauged streamflow volume for the Chickahominy gage the same five-year period. The ratios are ranked by precipitation, with the driest periods on the left. The ratios change fairly smoothly; more than 4 gallons of precipitation are required to make a gallon of streamflow during dry times, whereas in the wetter periods it takes less than 3. The two exceptions to the smooth transition are from the first two years of the stream gage measurements, 1942 and 1943. The higher amounts of water needed in the dry periods may be attributed to higher evaporation rates and greater absorption in the basin soils. To the extent that there is base flow – leakage from groundwater into the stream - the ratio may ultimately be attenuated, since base flow is possible with no precipitation at all.

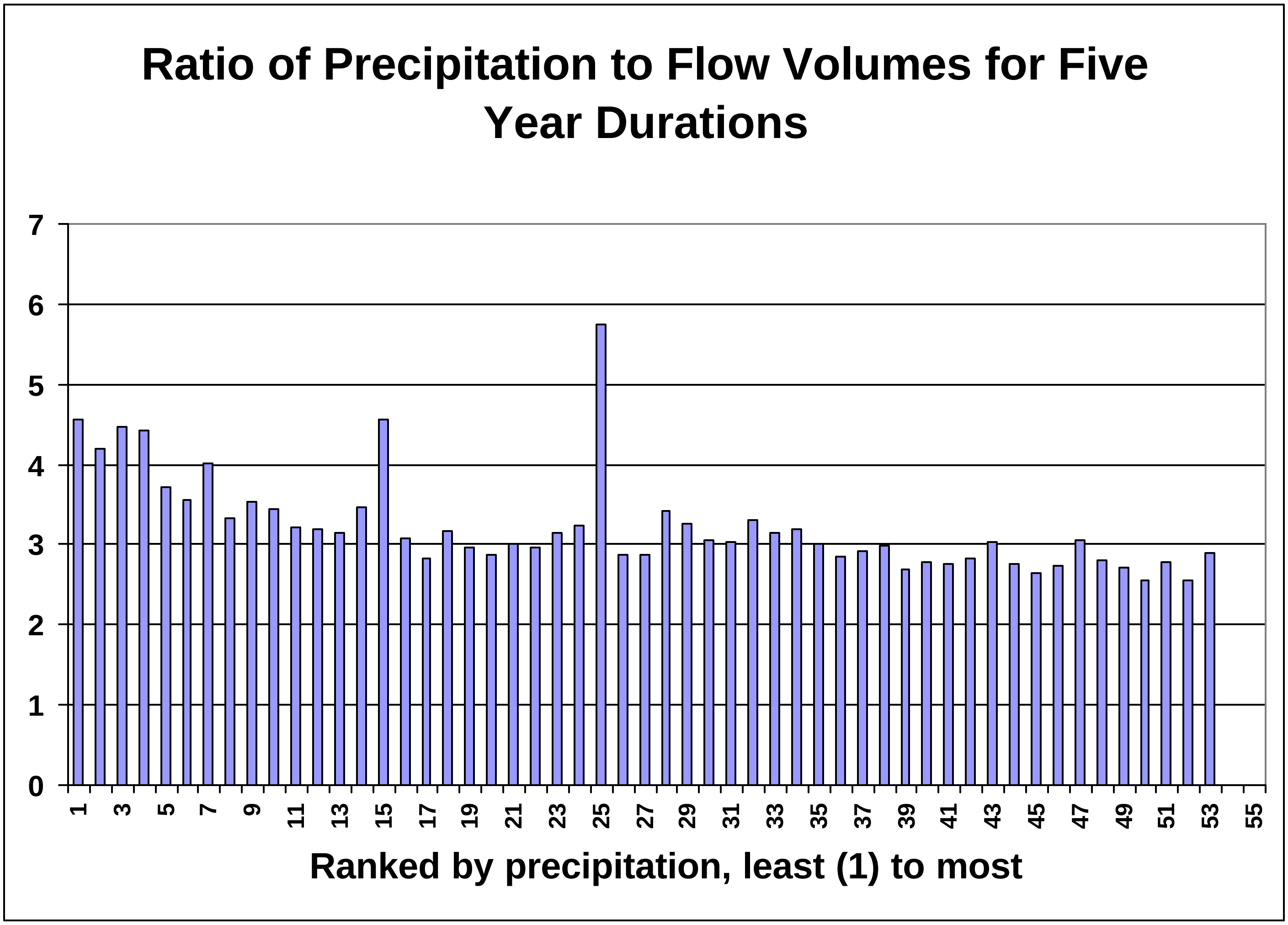

Figure 6. Precipitation to streamflow volume ratios for gauged flows, 1942-1999

Applying the same graphing approach to compare the extended streamflow and precipitation volumes shows a much less smooth transition (see Figure 7, next page).

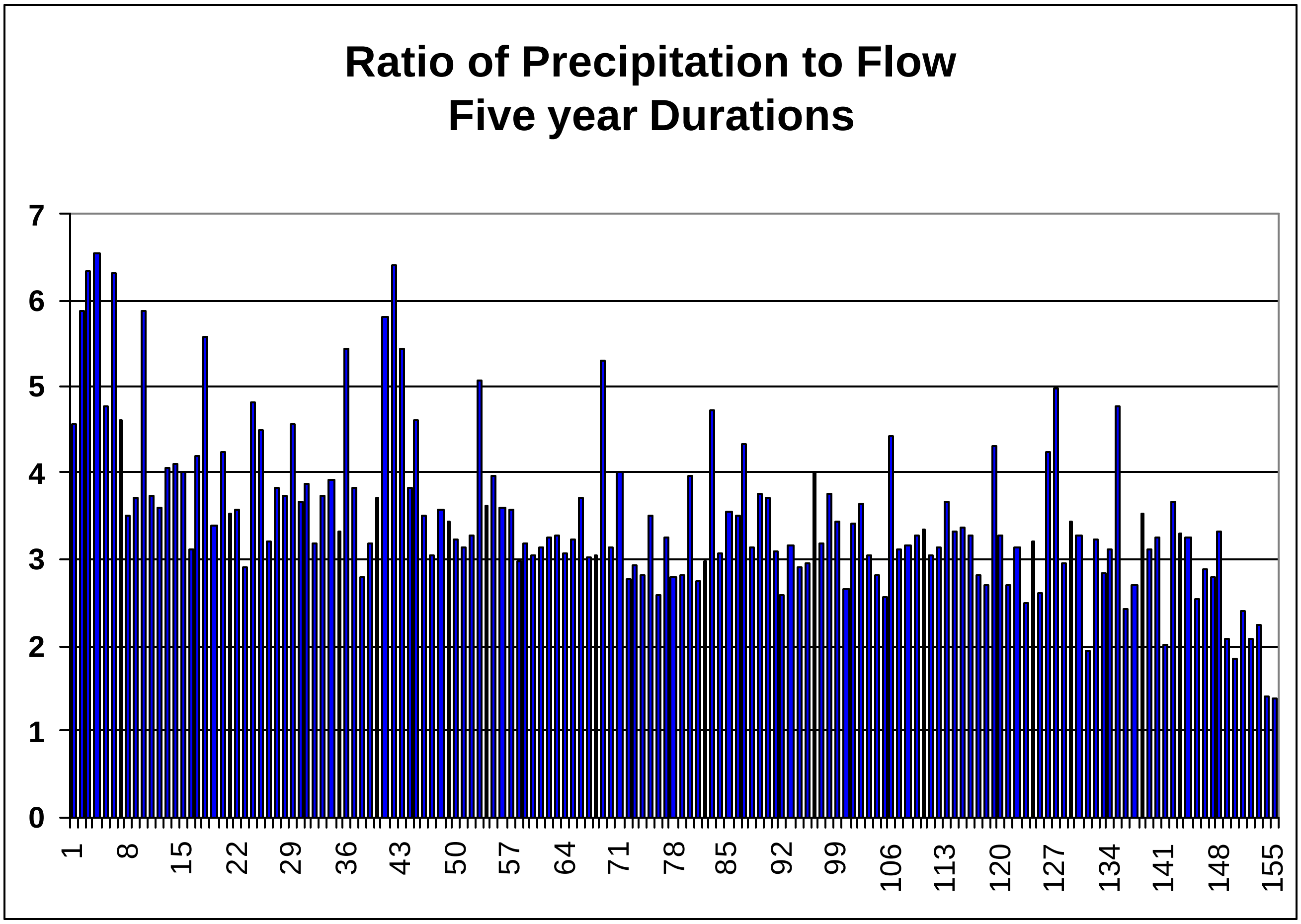

Figure 7. Precipitation to streamflow volume ratios for synthesized flows

The highest ratio (6.5) is from the five-year period starting in 1854. That means that streamflow generating method produced very little flow relative to the volume of rainfall. Disregarding the many outliers, the approximate ratio shift from 5 to 3 can still be seen, but the drought of record includes some of the outliers. According to the Atlas, the 1000-year return interval drought would provide about 50% of average rainfall. Assuming a ratio of 4.5 as opposed to 3 for the mean precipitation, over a five-year period one would expect about a third of the normal streamflow during a 1000-year drought. The worst five-year period in this synthesized data set contains about 35% of the average streamflow.

The estimate of recurrence intervals beyond fifty years is problematic, but the analysis above suggests something like a 1000-year recurrence interval for the streamflow. Droughts like this will occur, but the chance that they will occur in a given year is very small.

The Panel recognizes that any method of streamflow generation could be challenged. The flows from the 1850s can be used as the basis for planning for extraordinary droughts, but should not be used in a calculation of safe yield. In the typical simulation of safe yield, failure in 1 year out of a 100 is estimated as a 1% risk of failure. That assumes that the sample frequency of the worst drought on record is a good estimate of the true (population) frequency. There is good reason to believe that is not true in the cases of the 1850s drought in this extended streamflow data.

Dead Storage

Dead Storage. Adding reservoir storage space can increase the safe yield of a system up to a maximum that approaches the average inflow. Safe yield is generally calculated assuming reservoir capacity is diminished by dead storage. This space can be filled with years of sedimentation, and it can be difficult or expensive to release or pump or treat water in the lowest elevations. A March 1, 1996 DEQ memo states that:

- The Waterworks Regulations allow considerable discretion with the amount of dead storage
- The Camp Dresser McKee study says that true dead storage is 11.8% of total storage and Newport News could get a waterworks certificate based on this value from the Health Department.
- Newport News has chosen to use 33% of existing total storage as dead storage . . . we question the need for an extra reserve especially.

IWR developed its own safe yield models to determine the sensitivity of safe yield to the specification of dead storage volumes, and we found that the safe yield increased by about 4.5 mgd when dead storage was reduced from 33% to 20%.

Recent studies of safe yield set dead storage at 33%. According to all reports, 10-12% of the reservoir capacity could not be used, at least not without extraordinary measures (see page 53). Setting dead storage this high eliminates nearly 3 billion gallons of storage. Previous estimates of safe yield using lower dead storage estimates also used very high evaporation estimates, so the effect of dead storage on safe yield cannot be inferred from a comparison of these studies. HDR reports that the safe yield is not sensitive to the amount of dead storage, and provides these estimates without reference to how they were calculated:

Table 15

Dead Storage Percentage	HDR Safe Yield, Newport News System
25	56.7
30	56.3
33	55.7

IWR used its own safe yield model and found that increasing storage did increase safe yield more noticeably. The figures are not directly comparable at each percentage because the IWR figures include Big Bethel and Waller Mill reservoirs, seepage and raw water transmission losses. However, the differences can be compared. HDR reports that safe yield would increase only 1 mgd if storage increased by 1 million gallons (reducing dead storage from 33% to 25%). The Panel's estimate indicates that the safe yield would increase by about 4.5 mgd.

Table 16	
Dead Storage Percentage	IWR estimate of Safe Yield, all reservoirs
12	70.8
20	65.6
25	62.2
33	56.7

Because the Newport Waterworks reported experiencing significant water quality problems when Diascund Creek Reservoir was drawn down to between 20 and 25% of total storage in 1983 and 1984, IWR developed its base estimates of the risk of shortfall using the 33% dead storage. There were no reports on the costs or the difficulties involved in treating this water, so the Panel also calculated the risk of shortage using less dead storage so that the water supply effects could be compared to the costs of water treatment. However, we are not aware of any estimates of the additional treatment costs for using water from the lower portion of the reservoirs.

Drought Management

In the course of the IWR Panel's review of the adequacy of the RRWSG water supply system, there has been much discussion of whether or not drought planning should be a part of water supply planning. Typically, drought planning is the process of identifying an array of drought management measures, usually organized into several stages of increasing stringency; and defining trigger points which determine when each stage will be activated and inactivated.

Whether utilities in the Lower Peninsula area will ever implement drought management measures is not the question here: it is likely that they will. Drought management is a cost-effective element of any water supply plan, whether or not the plan includes the King William reservoir. Sooner or later, every utility is faced with a potential deficit and must take various actions to prevent system failure. The deficit may arise from meteorological drought, from a contamination episode, or from pipeline or equipment failure. The actions taken in these circumstances--ranging from water use reductions to augmentation of existing supply capacity to emergency supply arrangements--are known as drought management measures.

Utilities, including Newport News, generally have such emergency plans. The questions considered here are:

- Should utilities have standing plans for response to unanticipated emergencies of all kinds that specify what measures will be implemented under what circumstances?
- Should the Plan be used to determine long-term capacity needs?

With respect to the first question, the Panel believes that it is a responsibility of all water supply utilities to develop and maintain comprehensive and effective drought management plans. Newport News Waterworks plan provides for three tiers (stages) including voluntary measures (Tier 1) and a range of mandatory measures (Tiers 2 and 3). There are specific triggers for starting and ending the curtailments.

The more controversial issue is whether future capacity requirements should be calculated on the assumption that drought management measures will be used. The argument for doing so can be illustrated by considering the alternative. For many years, water supply planners calculated future infrastructure needs by comparing forecast unrestricted water use to water availability under design drought conditions. The selected design drought was sometimes an event of known probability (e.g., a 50-year or 100-year drought), but more often an historic event (the "drought of record") with an unknown but small probability of recurrence. Assuming that the water use forecast and the hydrologic assumptions proved accurate, the result was a water supply system that would require drought management measures very rarely during the forecast period (only for events more severe than the design drought).

But as hydrologic modeling, water use forecasting, and risk analysis methods improved, it became clear that planning on the basis of an arbitrary reliability level (e.g., for a 50-year drought) risks substantial excess costs. Setting the reliability level too high requires the utility to provide costly and possibly environmentally damaging supply works that will rarely be needed. Setting the reliability level too low means that costly, inconvenient, and potentially disruptive drought management measures will be implemented too frequently. Some advocate a low reliability strategy (planning for severe shortage restrictions) on the assumption that few if any supply projects are in the public interest and that a continual threat of shortage has beneficial effects on resource use. The Panel does not support this view. A preferable planning criterion is to minimize the total costs of supply and demand measures, achieving a balanced strategy of capacity additions and reasonable use of drought management.

But, in practice, the tradeoff is more complex than suggested by these basic principles. Some drought management measures, when implemented occasionally, involve little more than mild to moderate costs and inconvenience for water users. These include restrictions on outdoor water use, voluntary reductions, increased recycling, accelerated leakage control programs, etc. The availability of such measures in time of drought will often produce significant and highly cost-effective reductions in long-term supply requirements.

But, in order to be prepared for any eventuality, a utility must include a variety of additional measures in its drought management plan. Some of these are economically disruptive (requiring certain commercial and institutional activities to close, or industrial activities to scale back operations). Others involve environmental or water quality impacts (relaxing previously agreed-upon streamflow minimums or dead storage levels, utilizing emergency water sources, etc.). Even the least costly drought management measures can be politically or socially disruptive if they are implemented too frequently. For example, past experience with drought restrictions may interfere with economic development, or cause political repercussions. The magnitude of the disruption depends upon local conditions and the frequency of drought restrictions. Because these impacts go beyond the simple economic calculus proposed above for water supply planning, water supply planning usually maintains the probability of such outcomes at a very low level (e.g., once in 100 years).

With these caveats, the Panel supports consideration of drought restrictions as a part of water supply planning, because it so often makes economic and environmental sense to reduce use during occasional dry periods. Different regions have different perspectives on drought curtailment. The HDR report supports the use of drought restrictions and notes they have been used by Newport News even when there was little chance of a supply shortfall. The Panel recognizes that tolerance for drought curtailment varies from region to region and therefore relied on the Newport News drought plan for its analysis of feasible measures and their likely effect on water use.

Planning for Droughts More Severe Than Any on Record

The IWR Panel recommended that the region consider droughts more severe than the drought of record. As previously discussed, the Panel believes RRWSG did a credible job of estimating such a drought, although the Panel believes it should be considered a 1000 year drought rather than a 162 year drought. Suffice to say, this is a drought that could happen, perhaps similar to the drought that some believe destroyed the Jamestown settlement in the 1600s.

The Panel made it clear that it was not recommending that the region plan to have enough water to survive a drought of this magnitude without drastically reduced water use. IWR estimates that the safe yield of the RRWSG system would be reduced from 67 to 53 mgd (including surface and groundwater sources). Allowing the reservoirs to drop to 12% dead storage and using the current drought plans would support an average use of about 68 mgd, about the level of demand expected in 10 to 15 years. The use of the drought plan would entail a few months in Tier 3, during which costly reductions in water use (below winter use levels) would be required. At average use levels above 68 mgd, water use would have to be curtailed more, sooner or longer.

Still, it is instructive to note that very strenuous drought management measures have been used in the past and will be used in the future. For 16 months from May 1975 to August 1976, England and Wales experienced a drought much more severe than any recorded or remembered event.

Although such extrapolations are inherently suspect, the recurrence interval of the meteorological event was estimated at approximately 1,000 years. As the magnitude of the drought became clear, the then-recently organized (since dismantled) Water Authorities deployed the full range of known drought management measures. Every attempt was made to reduce water use, streamflow minima were relaxed, reservoirs were pumped dry, emergency wells were drilled, temporary interconnections constructed, and large amounts of water moved by tank truck. The flow of the lowest reaches of the Thames River was reversed by pumping back over the Teddington and Molesey Weirs, so that inflows from downstream tributaries as well as fresh water on the surface of the estuary could be moved to the Queen Mary Reservoir (serving Greater London). In some communities, distribution systems were de-pressurized for as much as 16 hours per day; in other cases residential areas were shut down completely, requiring households to carry water from public taps. Despite heavy costs and significant disruption, England and Wales survived the drought without catastrophic or lasting impacts.

Every water utility faces a non-zero but <u>very</u> small risk of an event similar to that experienced by England and Wales. Water supply planning should insure that such events remain rare, and drought management plans should provide effective means for dealing with them if they do occur.

The focus of this report, however, is on the other end of the drought management spectrum: the familiar, relatively low-impact measures which can be implemented from time to time to deal with small supply deficiencies. Typically, these measures are acceptable to the public (unless implemented too frequently) and less costly that the incremental supply capacity that would be required to avoid their use. Ideally, the expected cost of drought management measures is traded off against the corresponding cost of incremental supply, so that a minimum cost strategy can be identified. In the present case, no cost data on drought management measures have been provided. Instead, HDR suggests that only voluntary drought management measures should be considered in supply planning (Tier 1), and further proposes that capacity requirements based on the 1930s drought sequence (earlier droughts are more severe) should not consider drought management at all.

This misses the point at several levels. Whether or not planning is based on the 1930s drought is a separate matter that has no bearing on the relevancy of drought management. The Panel believes that low-impact drought measures should always be considered in determining supply requirements, whether implemented through voluntary action or by regulation. For example, occasional restrictions on outdoor uses of water, though mandatory, are generally regarded as low-impact. However, in considering any drought management measure, attention should be given to the frequency of use. In the absence of benefit and cost data, the maximum acceptable frequency becomes a matter of judgment. To assist in making this judgment, the Panel's risk analysis estimates and tabulates the frequency of use of assumed drought management measures.

Strategies for using groundwater as a drought mitigation tool or for meeting peak demands.

The Malcolm Pirnie model assumes that groundwater extraction wells will continue to be operated as they have been in the past. The simulations were developed using 6-month stress periods. The pumping rates are held constant during these 6-month periods. Ground water wells could be "rested" during periods when surface water supplies exceed demand. These wells could then be used to meet peak demands during drought periods or during high-demand periods. Other options for groundwater management are available, including aquifer storage and recovery. Aquifer storage and recovery involves injecting water during periods when there is a water excess and then extracting the water at a later date. The costs associated with this approach may be significantly greater than current costs for groundwater supplies, but they may be lower than other alternative sources. The Panel has insufficient information to determine whether this is a viable alternative, but was not aware of any analysis showing it was not.

Estimation of Safe Yield

Although there is room to argue about some points, the HDR risk assessment of water use is essentially sound and sophisticated, but its reporting of future water deficits overstates the risk.

No one can precisely predict what water supply or water use will be in 2050, but we can say that the uncertainty about future supply is different from the uncertainty about future demand, and the risk assessment must be structured to reflect those differences.

- We expect a gradual increase in water use over the decades, but with relatively little variance from year to year. There is substantial uncertainty about how much water the region will use in 2050 (HDR estimates it could be as little as 60 or as much as 95 mgd), but 2050 use will be fairly close to the amount used in 2049 and 2051. HDR properly assigned ranges to point estimates to capture this uncertainty.

- The safe yield is the minimum amount of water the system will produce over a long period of time. By definition, the system will almost always produce more water. HDR assumed that the probability that system yield would be between 50.6 mgd and 60.2 mgd was 100%, when by all estimates, there is only a 1 or 2% chance that the yield will be that low.

IWR developed its own yield model for the five reservoirs in the Newport News system to estimate the probabilities of satisfying various levels of demand in all years – not just the drought of record. We built the model according to the system descriptions provided in the FEIS and subsequent reports. The model can be used to estimate the yield of a larger system, including Big Bethel and Williamsburg's Waller Mill Reservoirs. All seven reservoirs compete at least to some extent for the same Chickahominy flows. Using the 1920-1999 segment of the extended streamflow record, we estimated a safe treated water yield of surface water sources as 56.7 mgd. This is essentially the same as the 56.5 mgd estimate reported by HDR. The IWR model uses the CD&M factors for monthly water use and net evaporation. Seepage and raw water distribution losses are calculated within the model. Seepage is 3 mgd when reservoirs are full and is reduced proportional to reservoir storage. Distribution losses vary from 1 to 3 mgd.

The results of our modeling indicated the combined surface and groundwater systems would supply 80 mgd in 89% of over the record. That compares reasonable well with the Malcolm Pirnie estimates of 90% reliability at 79 mgd in the "Cost of Alternative Water Supply" study. The use of drought contingency plans reduces shortfall volumes but only slightly increases the reliability of the system (to 95% at 80 mgd). The reduction of the dead storage estimate makes a greater difference (an increase to 99% reliability at 80 mgd when dead storage is reduced from 33% to 20%).

Dead storage and the safe yield of the Newport News system

In our previous report, we pointed out that the FEIS estimate of the safe yield of this system was based on a higher level of dead storage space than used in previous studies or required by the Virginia Department of Health. The average available flows in the Chickahominy are over 200 mgd; with enough reservoir capacity, the safe yield of the RRWSG surface water supply system could approach excess of the average flow rate over any required downstream releases. The Newport News system has about 13 billion gallons of storage, and Big Bethel and Waller Mill reservoirs add another 2 billion gallons. The difference in storage capacity at 11.8% and at 33% dead storage is almost 3 billion gallons, a little less than the volume of Diascund Creek reservoir. Tabular results from previous studies indicated that reducing the dead storage to the 11.8% or so used in previous studies would add about 5 mgd to the safe yield.

In doing this analysis, though, we realized that the difference would be even larger because the FEIS study also corrected an error that had reduced the yield in the older studies. Safe yield studies have to account for the amount of precipitation that falls directly on the reservoir and for the amount of water that evaporates from the surface of the reservoir. The old studies assumed an annual evaporation rate of over 2 feet, and did not distinguish between precipitation on the reservoir and precipitation on the surrounding land. The FEIS study reduced the previous estimate of local drainage by the surface area of each reservoir, but then algebraically combined precipitation on the reservoir and evaporation from the reservoir to get net reservoir evaporation. The resulting net annual precipitation is 8.9 inches, about one-third the original estimate. The effect in the older models, slightly buffered by the greater local inflow, was lower safe yields because of unrealistically high evaporation losses.

The safe yield of Big Bethel and Waller Mill reservoirs.

HDR's point estimates of the treated water safe yields of Big Bethel and Waller Mill reservoirs are 2 and 2.9 mgd. IWR analyzed the safe yield of these reservoirs separately and in conjunction with the Newport News reservoirs (since the inflows to all reservoirs compete to some extent for the same protected flows on the Chickahominy River) and developed similar estimates.

Alternative probability distributions for the groundwater yields

Based on our analysis of groundwater we used the following probability distributions for groundwater yields in the IWR risk assessment.

Newport News Waterworks

HDR study: Point value equal to 5.7 mgd (no uncertainty)
IWR: Same as HDR

Williamsburg

HDR study: Point value equal to 0.67 mgd (no uncertainty)
IWR: Same as HDR

James City Service Authority

HDR study: Triangular distribution.
Min = 2.3 Most likely = 4.9 Max = 4.9 mgd
IWR: Triangular distribution.
Min = 2.3 Most likely = 4.9 Max = 6.3 mgd

The upper value of 6.3 mgd was developed based on the simulations presented in the Malcolm Pirnie report. These simulations suggest that the yields from the Chickahominy-Piney Point aquifer could be increased from 5 mgd to 7 mgd without excessive drawdown. The simulations were developed assuming flow rates from all existing wells are increased by 40%. The James City Authority currently derives 3.6 mgd from the Chickahominy-Piney Point aquifer. If this increases by 40%, the total from the Chickahominy-Piney Point aquifer would be 5.0 mgd. The remaining 1.3 mgd is from deeper aquifers and is assumed to be constant. This results in a total yield of 6.3 mgd.

York County

HDR study: Triangular distribution.
Min = 0 Most likely = 0.63 Max = 0.63 mgd
IWR: Triangular distribution.
Min = 0 Most likely = 0.63 Max = 0.88 mgd

The upper value of 0.88 mgd was developed using the same approach that was used for the James City Service Authority. York County currently derives 0.63 mgd from the Chickahominy-Piney Point aquifer. If this increases by 40%, the total from the Chickahominy-Piney Point aquifer would be 0.88 mgd.

It should be noted that the revised distributions are still somewhat conservative because they do not include future wells that might be developed in deeper aquifers, including the brackish treatment system proposed by the James City Service Authority. These revisions also do not consider the benefits that could be derived by more diffuse groundwater extraction - they are based on simulations that assume all new groundwater development will be from existing wells. Finally, the simulations used to derive these revised distributions were developed assuming relatively small leakance values, as discussed above.

Risk of Shortages in the Future

Development of the Panel's Monte Carlo Simulation

HDR used a Monte Carlo analysis (see page 22 for an explanation of this procedure) to estimate the likely deficits. HDR estimated probable deficits by combining demands and safe yields in a Monte Carlo analysis. The Panel feels that it was inappropriate to use just the safe yield and to combine estimates of surface water yield with estimates of demands and groundwater yields. Unlike demand, we expect surface water supply to be similar to the past, and we have an abundance of data on past supply. Unlike demand, we also expect surface water supply to vary substantially from one year to the next. The safe yield of the surface water supply is a measure of the minimum amount of water we expect from this system. The odds that the surface water supply will be more than the safe yield are very good, about 98% in any year.

The IWR Panel combined demands and groundwater yields in a Monte Carlo simulation to calculate the range of demands (and their associated probabilities) that would have to be supplied by surface water. We then used our simulation model of the surface water system to calculate the number of years this system would be unable to provide various amounts of water supply.

Drought Contingency Plans and Safe Yield. We calculated the risk of shortages as the percentage of years in the simulation (using 1920-1999 data) that this surface water need was not met. If there was a shortage in any month, the year was counted as a failure.

The Panel calculated these probabilities using two assumptions used by HDR, that the reservoirs could not be allowed to go below 33% of full, and that water use would not be curtailed during droughts. The assumptions on dead storage and drought curtailment used by HDR are at least arguable. The Department of Health has agreed to a much lower dead storage and Newport News has a drought contingency plan and has used drought curtailments. Accordingly, the Panel also calculated shortfall probabilities assuming 20% dead storage and the use of drought curtailments.

IWR previously recommended that costs and benefits of long-term water and short-term water supply and demand plans be evaluated together on the basis of the costs and benefits they produce. Doing so can produce estimates of how often drought restrictions will be needed and how the costs of various degrees of drought curtailments compare to the costs of alternatives to permanently increase water supply. Since there were no benefit-cost analyses of drought curtailments in this set of studies, IWR used the existing Newport News drought plan and the Panel's safe yield model to determine how drought plans extend the reliability of this water system. We found that the Newport News plan can increase the reliability of the current water system; that is, if water use is curtailed occasionally during moderate to severe droughts, the system can support larger average demands without ever experiencing a shortfall. However, the already low outdoor water use in this region means that drought curtailment will not have the dramatic effect that is has in other regions of the country that rely on treated water for most domestic irrigation.

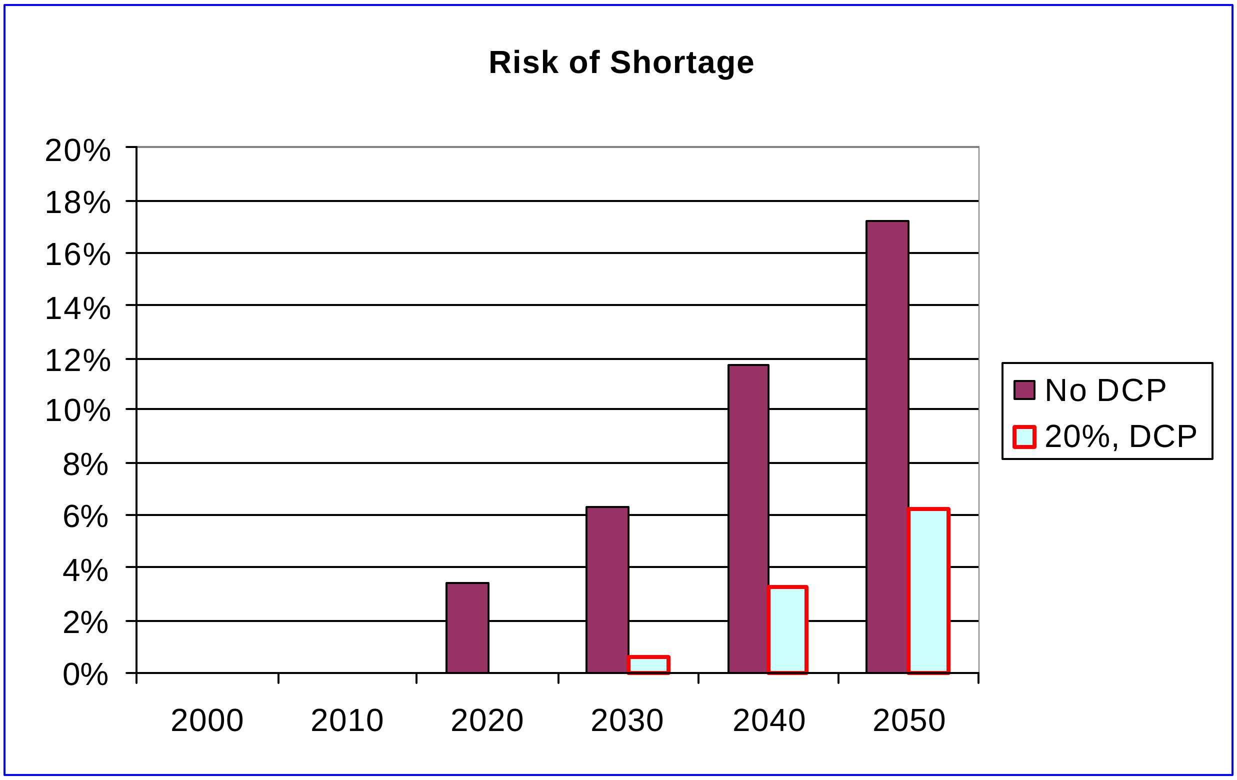

Figure 8. Probability That The Existing Water Supply Will Be Inadequate

We re-ran the simulation applying drought curtailments according to the rules and expected savings described in the Newport News drought contingency plan and allowed the reservoirs to drop to 20% dead storage to quantify the reduction in risk that would occur if the operators drew the reservoirs down more during droughts, recognizing that there could be additional water treatment costs. We counted the frequency with which drought curtailments were imposed. The results of these model runs are shown on the next few pages.

Figure 8 shows the risk that current water supply will be inadequate in each of the forecast years under the two assumptions; (1) 33% dead storage and no drought curtailments, and (2) 20% dead storage with drought curtailments. Under the first assumption, the Panel estimates the region will need more water by 2015. Based on the use of 20% dead storage and drought curtailments, the Panel believes the region will need more water supply by about 2025.

The frequency of drought curtailments for the second scenario is shown in Table 17, below. As might be expected, there appears to be a breaking point between 2020 and 2030 in which the frequency of voluntary drought declarations reaches a level at which many utilities would hear some public pressure for additional supplies. In 2020, voluntary lawn sprinkling bans would be required in 4 years out every 100; by 2030, mandatory bans would be imposed in 2 years of 100, but voluntary bans in 15 of 100. The voluntary percentage is high, but probably could be adjusted lower with a refinement of the triggers used. However, if future water use attains the high end of the expected range, supply would be inadequate even with these plans in place. This creates the small risk shown in Figure 8 for 2030 for the 20%, DCP scenario. By 2040 even with drought curtailments imposed in 1 year out of 2, there is a 4% risk of shortfall.

Table 17 – Frequency at Which Each Tier of Drought Curtailments are Imposed						
	2000	2010	2020	2030	2040	2050
Tier 1	0.03%	0.108%	3.4%	14.5%	45.9%	62.9%
Tier 2	0.00%	0.004%	1.3%	1.9%	4.0%	13.8%
Tier 3	0.00%	0.000%	0.5%	1.2%	0.0%	1.3%

How Additional Supply Would Effect the Risk of Shortfalls

Because of the uncertainty regarding the net yield of the other supply sources, particularly the proposed James City County Desalination Plant, the Panel estimated how various levels of additional supply would affect the risk of shortfall. Newport News argues that the net contribution of the desalination plant to the yield of the system would be only 2, not 5-6 mgd because some of the freshwater wells would be abandoned. The Panel's analysis of groundwater studies suggests that the current aquifer yields can be sustained, and so for planning purposes the expected net yield of the desalination plant should be estimated at between 2 and 6 mgd.

Figures 9 and 10 show the risk that supply will be inadequate with additional supplies of 5, 10, 15, 20, 25 mgd under the two operational assumptions. Supply is considered inadequate in any year where water use is not satisfied in any month. The analysis considers the worst drought in the 20th century, as Virginia rules require. The risk percentages shown capture the full range of probable demand and supply, not just point estimates.

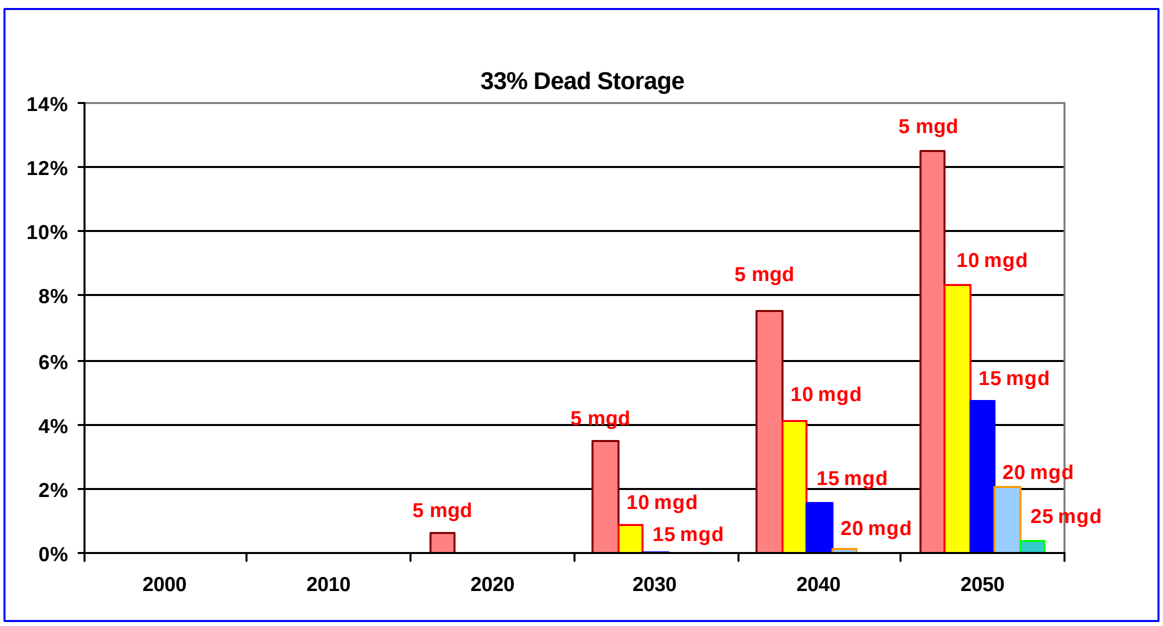

Figure 9. Probability That Water Supply Will Be Inadequate If Supplemented By New Supply, Assuming No Curtailment During Drought And 33% Dead Storage

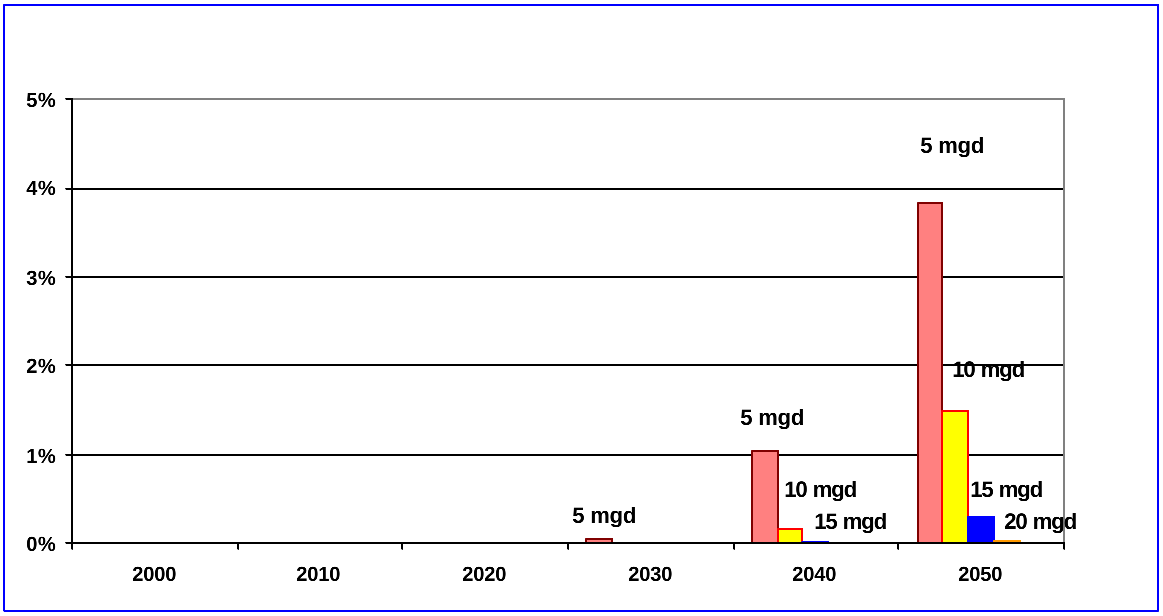

Figure 10. Probability That Water Supply Will Be Inadequate If Supplemented By New Supply, Assuming Curtailment During Drought And 20% Dead Storage

To reduce the risk to zero, the following amounts of additional water supply would be needed (Table 18 and Figure 11, next page):

Table 18 - Additional supply needed to eliminate risk of shortage						
	2000	2010	2020	2030	2040	2050
No DCP, 33%	0	0	11	17	25	32
DCP, 20%	0	0	0	8	16	23

These amounts correspond to the upper limit of Figure ES-1 in the HDR Report and represent the supply needed if future water use equals the highest estimated use in each category and future groundwater yields are the lowest forecasted yields.. These values are derived from a risk assessment that assigned a range to each water use category to capture the uncertainty in forecasts. Zero risk means that this amount of water would satisfy the highest levels of water use in those ranges under any of the hydrologic conditions experienced in the twentieth century.

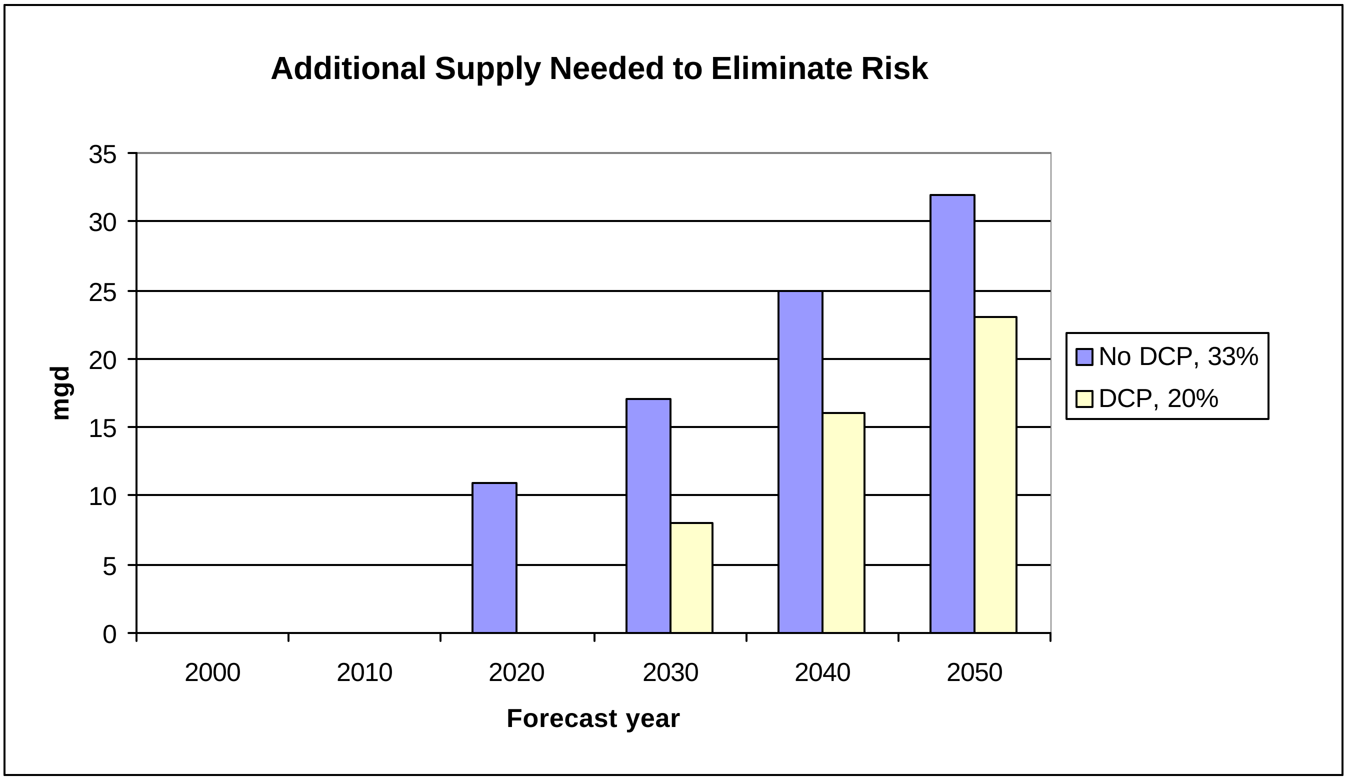

Figure 11. The amount of additional supply needed for zero risk of shortages

Conclusions

1. The Panel finds that its prior recommendation of a collaborative risk assessment for future water supply needs has been at least partially satisfied by the new studies reviewed here. It can be noted that the scope of collaboration was significantly limited (perhaps inevitable given the history of this permit application) as was the consideration of many of the economic and social variables, which could impact the acceptability of various outcomes.

2. The demand forecasts prepared by HDR are a substantial improvement over those previously presented in the FEIS. The water use models used for the point forecasts remain relatively simplistic, but the treatment of uncertainty in these forecasts is handled appropriately and competently.

3. The Panel has reviewed and tested all components of the HDR demand forecasts, and has replicated both the point forecasts and probability distributions. In preparing its own demand forecasts, the Panel has accepted nearly all aspects of the HDR forecasts but takes exception to several details, as follows:

- HDR assumed that the utilities of the RRWSG would serve 100 percent of the service area populations by 2040. Given the characteristics of the study area, the Panel finds an end point of 100 percent coverage to be highly unlikely. Moreover, the change in assumptions is not justified or supported in the HDR report. The present coverage is approximately 92 percent; the FEIS assumed that this would grow to about 94 percent by 2040. The Panel has adopted a coverage end point of 98 percent for 2050 (96.4 percent in 2040).

- The HDR forecasts assume that unaccounted for water (UAW) will increase from its current level of 6.3 percent to 10 percent of treated water production by the year 2040. In its earlier review of the FEIS, the Panel accepted a similar assumption. Since then, new reports have provided additional information on UAW and water losses in general. Based on its review of current practices and operating results for Newport News Waterworks, and the fact that raw water transmission losses are excluded from the definition of UAW (they are included in supply losses by both HDR and the Panel), the Panel has adopted a UAW end point of 8.0 percent for 2040 and beyond.

4. The analysis of supply, presented in reports by HDR, CDM, and Malcolm Pirnie, is essentially sound and sophisticated. The Panel's own determination of safe yield for the 1926-1999 streamflow record closely replicated that given in the HDR report for the same data set.

5. Pursuant to a previous suggestion by the Panel, CDM synthesized a streamflow record for the 1838-1926 period in order to test the system against droughts more severe than the 1930 drought of record. The Panel has some problems with the methods used for this extrapolation, particularly as they affect rainfall/streamflow relationships. In particular, the Panel finds that CDM has underestimated the recurrence intervals of the most severe droughts. For example CDM describes the 1851-1855 drought as a 162-year event; the Panel's analysis indicates that the recurrence interval of the synthesized streamflow sequence for this event is approximately 1,000 years.

6. In preparing its supply forecasts, the Panel takes the following exceptions to the supply analysis presented by HDR:

- HDR considers only the safe yield of the supply system. The Panel finds that this approach exaggerates the risk of future deficits. In fact, actual supply will nearly always exceed safe yield. The Panel's supply forecast is a probability distribution of the full range of yields, from lowest to highest, so that the risk assessment can consider all combinations of supply and demand.

- HDR presents two safe yield estimates, one based on the 1930 drought (from the 1926-1999 streamflow records) and another, lower estimate based on the longer synthesized record. For the reasons noted above, the Panel has based its forecast on actual (not safe) yield indicated by the 1926-1999 records. The Panel recognizes that the synthesized 19th century streamflows could occur, albeit with very low probability. There are few references as to what a utility should do for an event this rare, but our analysis indicates that the region would need to reduce water use to below 85 percent of winter (indoor) use for several months, violate the low flow requirements in the Chickahominy or use the very lowest portions of reservoir storage.

HDR defines supply as treated water production. Among the adjustments required to derive this measure are reservoir seepage and raw water transmission losses. The HDR analysis combines treatment losses with reservoir seepage, with a stated point estimate of 4.0 MGD. The IWR model uses the CD&M factors for monthly water use and net evaporation. Seepage and raw water distribution losses are calculated within the model. Seepage is 3 mgd when reservoirs are full and is reduced proportional to reservoir storage. Distribution losses vary from 1 to 3 mgd.

- HDR assumed that the safe yields of wells in James City and York Counties could not increase. We believe that increases, while not certain, may be possible. This assumption is reflected by an increase in the upper bound for the probability distributions for these sources.

7. The Panel applied the Newport News drought plan (as documented in the FEIS) and found that it reduced shortage volumes and duration's and slightly increased the reliability of the system. Because of the relatively low level of unrestricted seasonal water use, the impact of drought restrictions is less dramatic than would be expected in other areas, such as the Western U.S.

8. The Panel finds that, if no new water sources are provided, the RRWSG service area will experience an increasing risk of deficit over the next 50 years. Assuming water use is not curtailed during drought and reservoirs are not allowed to go below 33% full, this risk will not be perceptible before about 2015, and is likely to become clearly perceptible sometime after 2020. Based on the use of 20% dead storage and drought curtailments, both of which have been used in practice, the Panel believes the region will need more water supply by about 2025.

9. The Panel also believes that James City County has shown its intent to develop a desalinated groundwater plant. HDR concluded the plant would probably be built, and the Panel believes it should be considered in the analysis as an alternative to the King William Reservoir. Newport News argues that its net contribution to the yield of the system would be only 2, not 5-6 mgd. The Panel's analysis of groundwater studies suggests that the expected yield will be between 2 and 6 mgd. Yield from this source would mean that the region will have adequate supply for a few years beyond the dates noted above.

10. There will be a sequence of tasks that must be accomplished before any new source of water is in place. If there are tasks that must be taken now to assure timely delivery of water supply when it is needed, then decisions on those actions should be taken immediately based on this assessment of need and other assessments of costs and impacts.

11. **Comparing IWR and HDR Results**. The Panel and HDR are very close in their estimates of future water use and supply. The Panel's estimate of probable 2050 demands is about 5% less than HDR's because we believe they overestimated unaccounted for water and market penetration. Our point estimate of groundwater yield is the same as HDR's, but our probabilistic estimate is a little higher because we allow for the possibility of higher yields. Our estimate of the safe yield of the current surface water supply is 56.7 mgd compared to HDR's 56.5 mgd. HDR concludes that the region will need more water by 2010, based on Newport News' use of 33% dead storage and the Virginia Department of Health's rule that utilities not rely on drought curtailments to assess the adequacy of their supplies. Based on those two assumptions, the Panel estimates the region will need more water by 2015. The biggest difference between the Panel and HDR is in how we present the results. HDR shows the probable difference between future water use and the minimum expected supply (safe yield). The Panel has criticized this approach in past reports, since the system will produce more water than the safe yield about 98% of the time. The latest RRWSG reports confirm this.

12. Notwithstanding the criticisms and exceptions described above, the Panel finds that the RRWSG has demonstrated a need for additional water supply sometime between 2015 and 2030 depending on the criteria used by decision makers.

13. There will be a sequence of tasks that must be accomplished before any new source of water is in place. If there are tasks that must be taken now to assure timely delivery of water supply when it is needed, then decisions on those actions should be taken immediately based on this assessment of need and other assessments of costs and impacts.

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